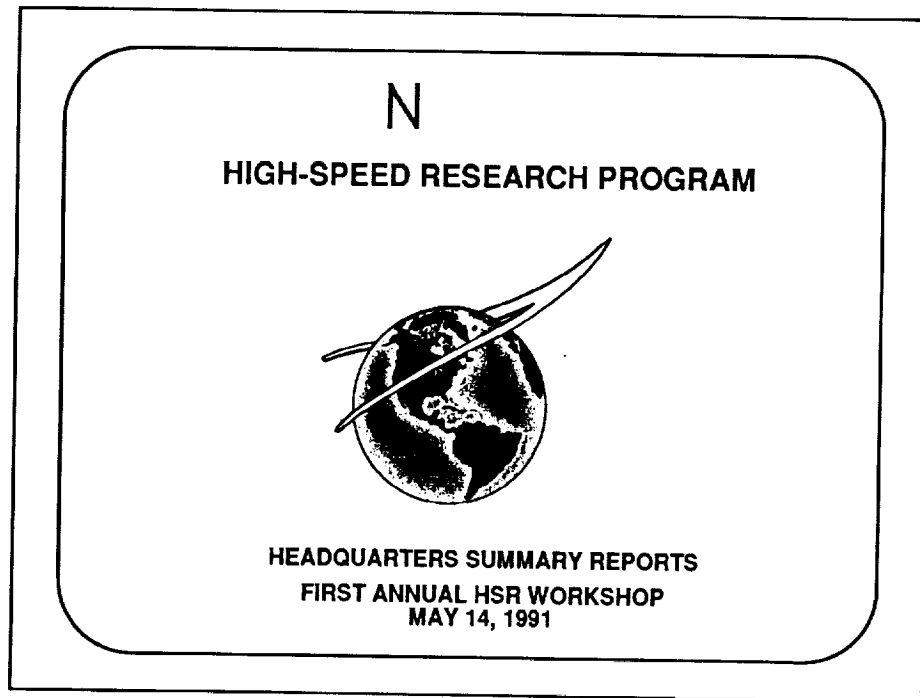


55-05  
12020**HEADQUARTERS SUMMARY REPORTS**

The purpose of this report is to summarize the status of the NASA sponsored involvement in high-speed civil transport research and technology, including major cooperative efforts. Of course, that involvement is currently focussed on the High-Speed Research Program.



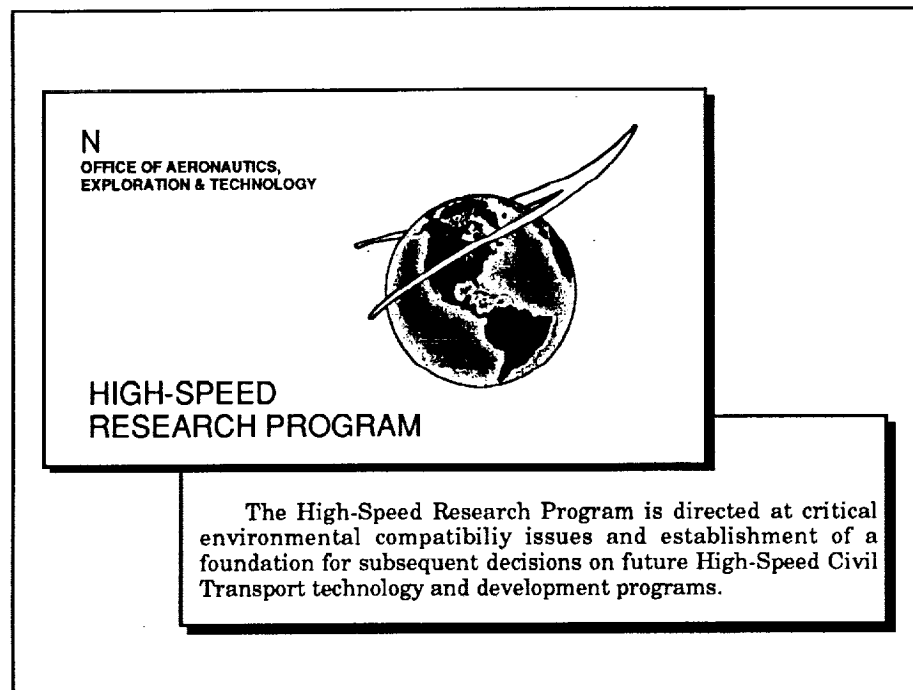
## HIGH-SPEED RESEARCH PROGRAM

The White House Office of Science and Technology Policy (OSTP) reports of 1985 and 1987 identified national aeronautical R&D goals directed at maintenance of U.S. aeronautical preeminence into the next century, and presented an action plan for achievement of the goals.

The goals address three areas of aeronautics -- subsonics, supersonics, and transatmospherics. The supersonics goal calls for development of technology for efficient, long-distance supersonic cruise for both future military aircraft and trans-Pacific-range supersonic transports.

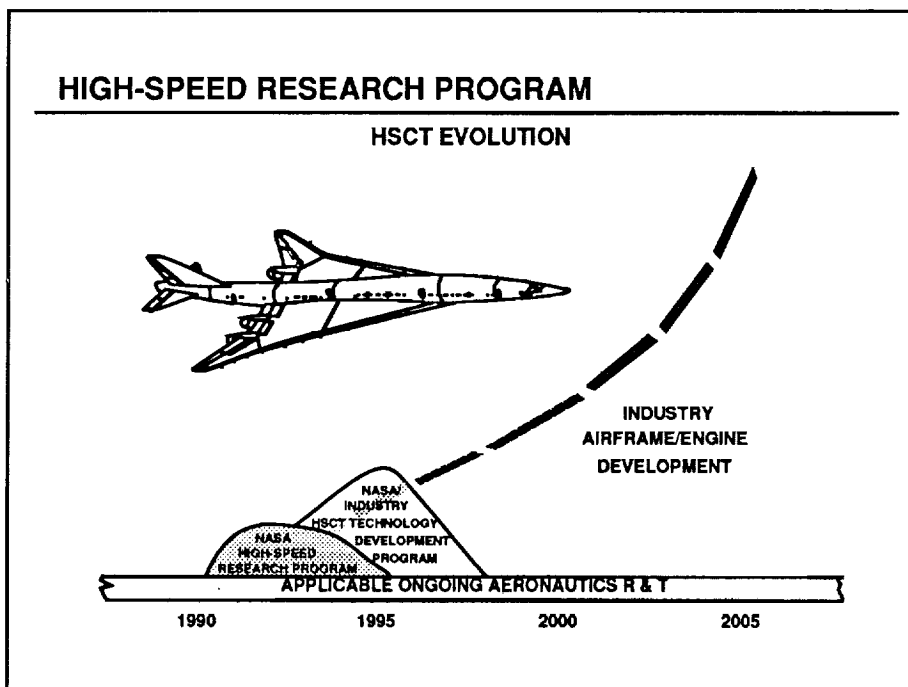
Consistent with this goal, and in view of the world market potential and international competition, the development of an updated technology base for high-speed civil transports -- with top priority and emphasis on the environmental barrier issues -- is an important and timely national research objective.

The NASA High-Speed Research Program is a direct response to meeting this national objective. It is an essential step which must be taken prior to initiating more focussed government/industry technology development efforts that could lead to future high-speed civil transports (HSCT). A principal challenge in this initial effort is to balance the often conflicting requirements of environmental compatibility and economic viability.



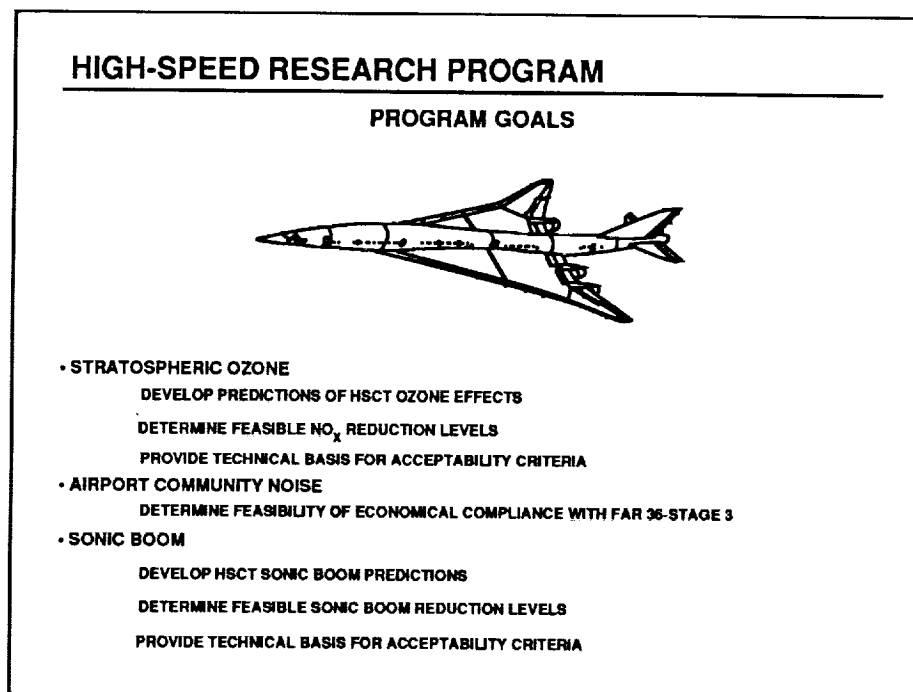
## HSCT EVOLUTION

The High-Speed Research Program (HSRP) is the first phase of a larger planned NASA technology development program. If solutions are identified for the barrier environmental problems, and system studies continue to indicate promise of economic success, a cooperative NASA and industry focussed technology program could begin, possibly in FY 93, that would complete a foundation for more costly airframe and engine development and production by the industry.



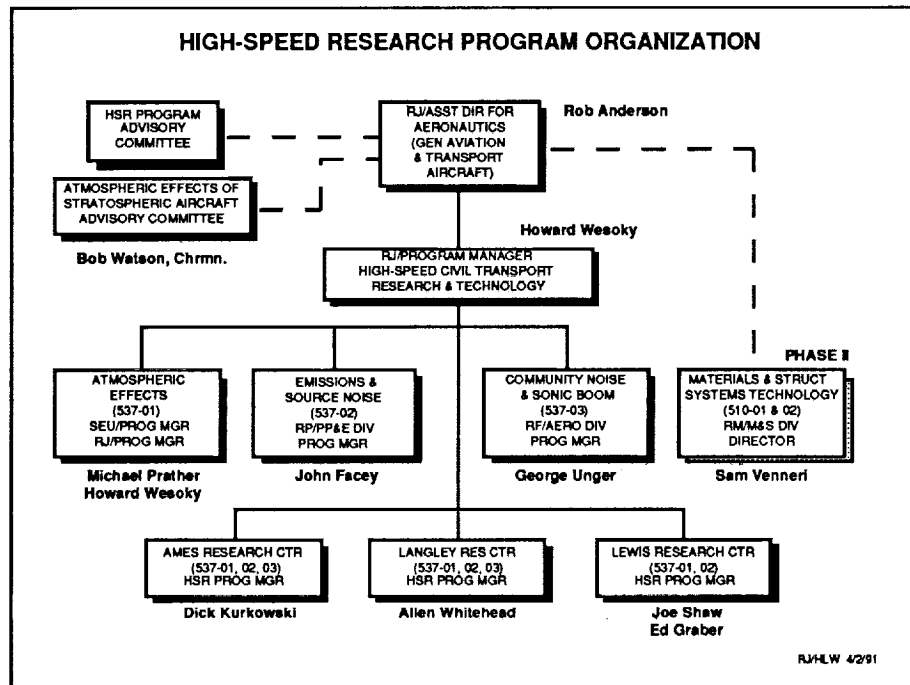
## PROGRAM GOALS

Acceptable levels of ozone depletion or sonic boom are not currently known, and definition of acceptability is a regulatory and political process. The HSRP goal is to provide technical bases for acceptability criteria. Community noise is currently regulated, and it seems clear that HSCT aircraft will have to comply with at least the spirit of the current subsonic constraint, FAR 36, Stage 3.



## HIGH-SPEED RESEARCH PROGRAM ORGANIZATION

Under the supervision of the Assistant Director for Aeronautics (General Aviation & Transport Aircraft) in the Office of Aeronautics, Exploration and Technology (OAET), responsibility for implementation of the HSRP is assigned to the Program Manager, HSCT Research & Technology to coordinate preparation of budgets and plans, monitor overall progress, and provide reports to OAET management. Headquarters management responsibility for specific disciplinary areas (i.e., RTOPs) of the HSRP are assigned to OAET and Office of Space Science & Applications program managers. Implementation of activities in the field is coordinated by Center HSR Program Managers. Two advisory committees assist in guiding the overall program and the atmospheric science assessment activity. Related HSCT materials and structures technology is currently being developed in a parallel systems technology program which is broad in scope, and is a precursor for the next phase of the HSCT technology foundation (aka Phase II).



## PROGRAM SUMMARY

The Headquarters managers will summarize the program status using a format which is similar to the program work breakdown structure. The NASA systems studies will not be covered here, as that work is primarily accomplished by the aircraft and engine manufacturers whose summary reports are provided elsewhere.

### PROGRAM SUMMARY

• INTRODUCTION	HOWARD WESOKY
• ATMOSPHERIC EFFECTS OF STRATOSPHERIC AIRCRAFT	MICHAEL PRATHER
• LOW NO <sub>x</sub> COMBUSTOR TECHNOLOGY	JOHN FACEY
• SOURCE NOISE REDUCTION	JOHN FACEY
• COMMUNITY NOISE REDUCTION	GEORGE UNGER
• SONIC BOOM MINIMIZATION	GEORGE UNGER
• SUPERSONIC LAMINAR FLOW CONTROL	GEORGE UNGER
• MATERIALS & STRUCTURES	SAM VENNERI
• WRAPUP & QUESTIONS	HOWARD WESOKY

## MILESTONE SUMMARY

This is a summary of planned program milestones from the HSRP Briefing Book, which was utilized for budget advocacy. As the six-year program schedule is now about 25% complete, some changes in plans are naturally occurring (i.e., typical for research and development), and an objective of this workshop is to assess related progress. Some program elements have seemingly progressed better than others, but, on the whole, the HSRP appears to be achieving important goals.

HIGH-SPEED RESEARCH PROGRAM								
MILESTONE SUMMARY								
ELEMENTS	1990	1991	1992	1993	1994	1995	GOALS	
ATMOSPHERIC EFFECTS	ATMOSPHERIC STUDIES						ASSESS EFFECTS OF HSCT FLEET ON ATMOSPHERE	
	2-D MODEL ASSESSMENT	DETERMINE MODEL UNCERTAINTIES	IMPROVE MODELS	COMPLETE ASSESSMENT				
	SYSTEM STUDIES						PROVIDE BASIS FOR EVALUATING AND GUIDING TECHNOLOGY	
	BASIS CONFIGURATIONS	ENGINE CYCLE SELECTION	ASSESS CONFIGURATION ECONOMICS					
EMISSIONS AND SOURCE NOISE	EMISSIONS						DEVELOP TECHNOLOGY FOR ACCEPTABLE REDUCTION OF EMISSIONS AND NOISE	
	ADDITIVES EVALUATION	FLAME TUBE COMBUSTION TESTS	VALIDATE COMBUSTION ANALYSES	COMBUSTION VERIFICATION TESTS				
	NOISE REDUCTION							
	CONCEPTS ASSESSED	VALIDATE AEROACOUSTIC ANALYSES	VERIFY NOISE REDUCTION					
COMMUNITY NOISE AND SONIC BOOM	COMMUNITY NOISE / HIGH LIFT						VERIFY COMPLIANCE WITH FAR 36 STAGE 3 NOISE LEVELS	
	UPDATE NOISE CODE	VERIFY NOISE PREDICTION	LOW-NOISE AIRCRAFT W.T. TESTS					
	SONIC BOOM						ASSESS LOW BOOM CONCEPTS	
	EVALUATE ACCEPTABILITY CRITERIA	LOW-BOOM FLIGHT OPTIMIZATION	VALIDATION					
	SUPERSONIC LFC						DEVELOP SLFC TECHNOLOGY	
	TRANSITION GLOVE TEST	3-D FLOW TRANSITION PREDICTION	COMPLETE FLIGHT TEST					

## MAJOR ACCOMPLISHMENTS TO DATE

The first interim assessment of HSCT atmospheric impact is now being documented, and important modeling and chemistry laboratory work is underway, along with planning for field measurements. Broad disciplinary application of computational fluid dynamics (CFD) has provided an analytical tool not available in previous SST efforts. In the propulsion area, important experimental confirmation of emissions and noise reduction has also been achieved. Wind tunnel tests of high lift devices have begun, and interesting piloted simulations are identifying related operational procedures for reducing community noise. Wind tunnel tests are also helping to confirm low sonic boom concepts, and subjective responses to the pressure signatures are providing additional guidance. For supersonic laminar flow control research (SLFC), preliminary design analysis and wind tunnel tests have been accomplished. The F-16XL aircraft which will be the focus for SLFC experiments is now at DFRF.

The major accomplishments for the related materials and structures research are provided later.

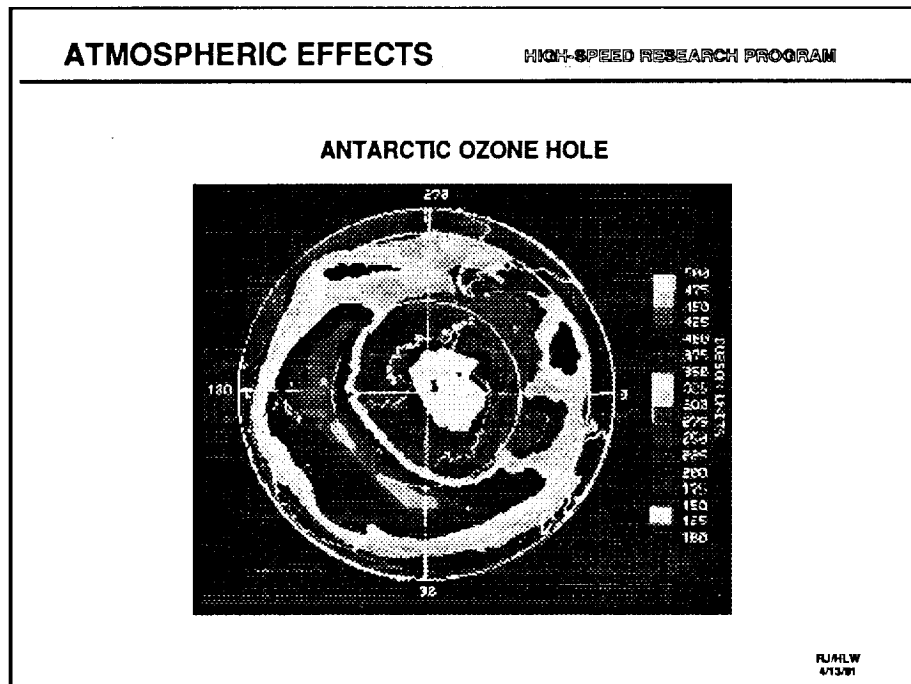
### MAJOR ACCOMPLISHMENTS TO DATE

- **ATMOSPHERIC RESEARCH**
  - 2-D MODEL ASSESSMENT
  - CHEMISTRY LAB EXPERIMENTS
  - FIELD CAMPAIGN PLANNING
- **EMISSIONS REDUCTION**
  - ADDITIVES EVALUATION
  - CFD APPLICATION
  - FLAMETUBE DEMONSTRATION OF LPP CONCEPT
- **SOURCE NOISE REDUCTION**
  - CFD APPLICATION
  - MIXER/EJECTOR NOZZLE AEROACOUSTIC PERFORMANCE
- **COMMUNITY NOISE**
  - ANOPP APPLICATION
  - HIGH-LIFT CONCEPT SCREENING
  - PILOTED SIMULATION OF OPERATIONAL PROCEDURES
- **SONIC BOOM**
  - CFD APPLICATION
  - PHASE I LOW BOOM CONCEPT W.T. TESTS
  - SUBJECTIVE RESPONSE EVALUATION
- **SUPERSONIC LAMINAR FLOW CONTROL**
  - CFD APPLICATION
  - FLOW MEASUREMENT PROCEDURES
  - F-16XL AIRCRAFT ACQUISITION



## ATMOSPHERIC EFFECTS

This well known plot of satellite data, which effectively pictures the Antarctic ozone hole, is representative of environmental concerns similar to those for HSCT operation in the stratosphere. Scientists from the NASA Upper Atmosphere Research Program (UARP), who have contributed to knowledge of CFC effects, are now applying this understanding to the HSCT ozone depletion problem. Worldwide scientific attention is being directed at the effects of man-made pollutants on the Earth's upper atmosphere, with particular attention to protection of the stratospheric ozone layer. As a major U.S. participant in this effort, NASA reports regularly to the Congress and to concerned agencies on the status of upper atmospheric research, and on scientific assessment of potential effects of human activities. These reports now include the Atmospheric Effects of Stratospheric Aircraft (AESAs) element of the HSRP.



## AESA SCIENTIFIC ADVISORY PANEL

The HSRP places primary emphasis on the understanding and assessment of atmospheric effects. As previously indicated, this research is guided by a committee representative of the international scientific community, and coordinated by leaders of the NASA UARP. Members include Professor Harold Johnston, who first identified the potential problem of ozone depletion by SSTs, other prominent academics, NOAA scientists, and a public interest organization scientist. The FAA and EPA are represented by ex-officio members, and aircraft industry observers participate in committee meetings.

### ATMOSPHERIC EFFECTS OF STRATOSPHERIC AIRCRAFT SCIENTIFIC ADVISORY PANEL

<u>Name</u>	<u>Affiliation</u>
Mr. Robert E. Anderson	NASA Headquarters
Dr. R. A. Cox	Natural Environment Research Council, UK
Prof. Frederick L. Dryer	Princeton University
Prof. Dieter H. Ehhalt	Institute for Atmospheric Chemistry, FRG
Prof. James R. Holton	University of Washington
Dr. Harold S. Johnston	University of California, Berkeley
Dr. Nicole Loulsnard	Office National d'Etudes et Recherches Aerospatiales, France
Dr. Jerry D. Mahlman	NOAA/Geophysical Fluid Dynamics Laboratory
Dr. Taroh Matsuno	University of Tokyo/Geophysical Institute
Dr. Mario J. Molina	Massachusetts Institute of Technology
Dr. Michael Oppenheimer	Environmental Defense Fund
Dr. Alan Plumb	Massachusetts Institute of Technology
Dr. Michael J. Prather	NASA/Goddard Institute for Space Studies
Dr. A. R. Ravishankara	NOAA/Environmental Research Laboratory
Dr. Adrian Tuck	NOAA/Aeronomy Laboratory
Dr. Robert T. Watson	NASA Headquarters
Dr. Steven C. Wofsy	Harvard University
Dr. Donald J. Wuebbles	Lawrence Livermore National Laboratory

## **"Stratospheric Models & Measurements: A Critical Comparison"**

### **The Role of HSRP/AESA**

*Michael J. Prather  
NASA/GISS, New York*

The High-Speed Research Program of NASA (HSRP) is charged with assessing by 1995 the environmental impact of a projected fleet of high-speed civil transports (HSCTs, a commercial supersonic aircraft fleet). In order to prepare for the assessment of chemical perturbations to the atmosphere from the proposed fleet, HSRP, through the Atmospheric Effect of Stratospheric Aircraft (AESA) studies, has supported basic research in atmospheric modeling, laboratory studies of chemical reactions, and instrument development. A stated intent of HSRP/AESA is to develop and validate the global chemical transport models (CTMs) that are the essential element of the program.

Assessment of the impact of aircraft exhaust (from *projected* supersonic fleets) on stratospheric chemistry, and particularly ozone, will rely on our 2-D and 3-D global atmospheric models. It has been duly noted at several meetings that the community has presented and published numerous model simulations for future scenarios, but that we have no objective (i.e., quasi-standard) criteria for judging which models are "reliable" for today's atmosphere. The extensive "2-D Intercomparison of Stratospheric Models" (September 1988, Virginia Beach, Jackman et al., NASA CP-3042, 608 pp.) went a long way toward documenting the similarities and differences among the available 2-D and 3-D models in terms of both chemistry, radiation and circulation. This model intercomparison was not immediately followed up by another because, for one, the community was exhausted, and moreover, the limitations of a model-model intercomparison had been pushed to the limit.

We are now taking the next significant step of a model-measurement comparison. Dr. Ellis Remsberg (NASA Langley) has consented to chair this effort that will culminate in an international workshop "Stratospheric Models & Measurements: A Critical Comparison" in early 1992. This new workshop will likely include some specific model-model intercomparisons that have not been adequately answered by the 1988 meeting (e.g., photolysis rates), but will focus on a set of measurements and parallel model simulations. The style will be similar to the last comparison, in which one individual (model or

data connections) would take one of the prescribed cases (e.g., total ozone) and cross-compare all model simulations as well as all the different measurements and their uncertainties. We will rely on the UADP database (Dr. Robert Seals, NASA Langley) as the repository for all observational data and model simulations, and as the source of the comparisons (graphic or tabular).

This effort is being organized by a core of researchers, primarily those involved in data analysis and includes only some representatives from the modeling community. This summer we will reach out to the remaining groups involved in HSCT assessments for HSRP/AESA or in CFC-related ozone assessments for the Montreal Protocol re-evaluation. This effort is an important new initiative in our community, and the responses from researchers in both modeling and measurements have been encouraging and even enthusiastic. My charge to this committee is

- (1) to establish a standard set of atmospheric measurements that can be used to test the reliability of atmospheric chemistry models,
- (2) to develop a method for evaluating model-data comparisons,
- (3) to direct the first major international stratospheric model-data comparison.

### **CALENDAR**

March 13-14, 1991 (DC area)

First committee meeting, define types of datasets and model runs.

May 15-16, 1991 (Williamsburg, VA)

Make final decisions on datasets and model simulations.

June-July 1991

Circulate letter with final definitions for Feb comparison.

Dec 1991

Models and Measurements must have data to Bob Seals.

Feb 1992

International workshop: stratospheric model-measurement comparison.  
A small group, no more than 32 participants.

HSRP / Atmospheric Effects of Stratospheric Aircraft  
Earth Science and Applications Division (OSSA/SE)

**HSRP/AESA Program Objective:**

Prepare for a 1995 Scientific  
Assessment of the Atmospheric  
Impact of a Projected Fleet of High-  
Speed Civil Transport Aircraft.

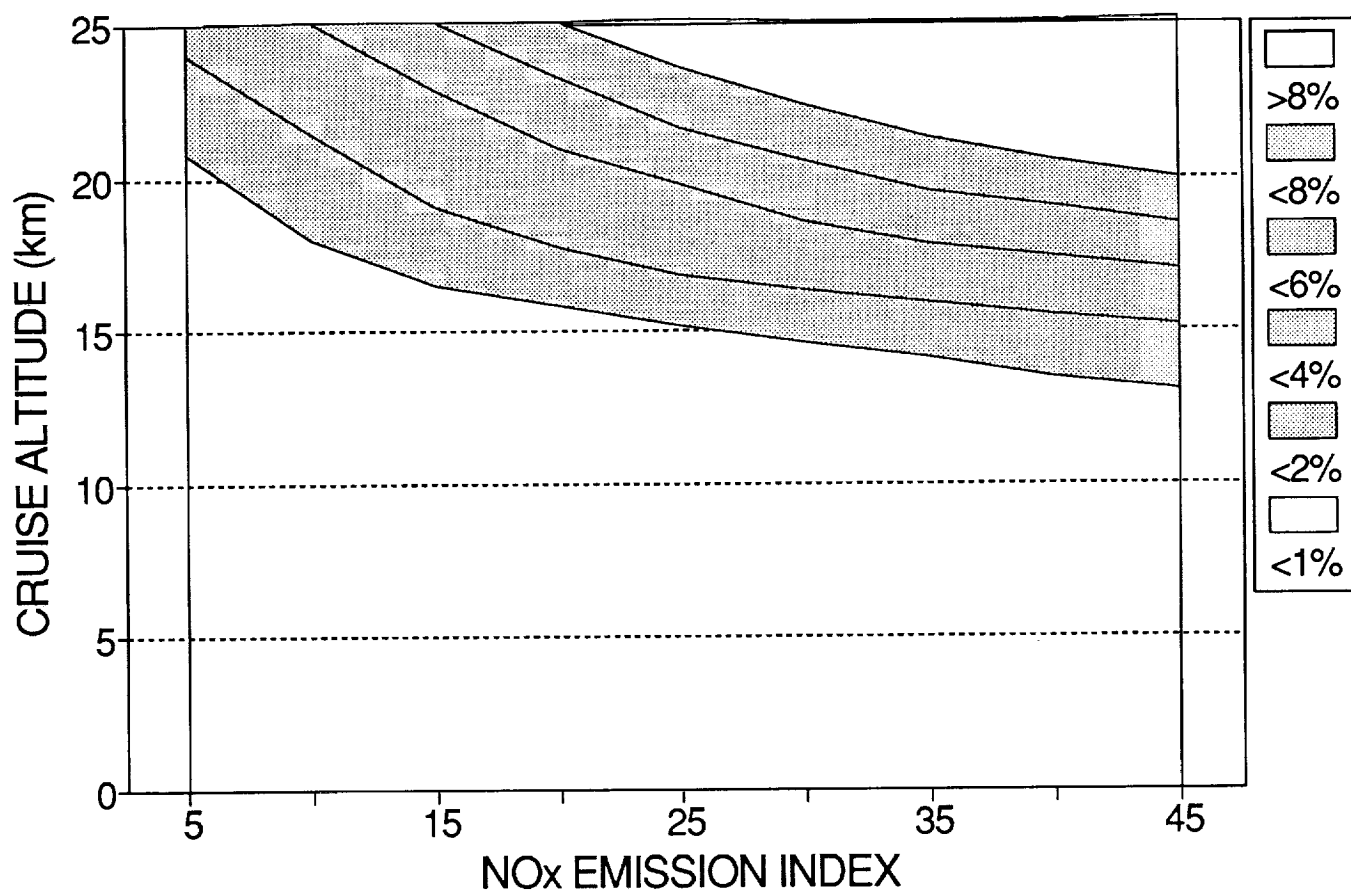
## HSRP/AESA: What is the Problem?

### *HSCT Emissions (Mach 2.4):*

<i>species</i>	<i>perturb. / natural background</i>	
CO <sub>2</sub>	1 ppm / 350 ppm	
H <sub>2</sub> O	1 ppm / 4 ppm	==> OH, HO <sub>2</sub> , climate
NO <sub>y</sub> (NO <sub>2</sub> )	4 ppb / 16 ppb	==> NO <sub>2</sub> +O → NO+O <sub>2</sub>
CO	1.5 ppb / 10 ppb	
hydrocarbons		
SO <sub>2</sub>		==> aerosol chemistry,
soot		radiation

# MEAN COLUMN OZONE DEPLETION (%)

(ref: Jackman et al, GSFC, 1991)



## **HSRP/AESA Components:**

### **Scenarios for Aircraft Fleet Emissions**

- 1. Engine Exhaust**
- 2. Fleet Scenario**

### **Predictive Global Models:**

- 1. Accumulation & Dispersion of Exhaust**
- 2. Resulting Chemical Perturbation**

### **Laboratory Studies of Chemical Mechanisms**

### **Current Atmospheric Measurements**

### **Identify Weaknesses, Quantify Uncertainty**



## **HSRP/AESA ACCOMPLISHMENTS**

- 1988    Forge OAET/RJ - OSSA/SE Link  
         Form Advisory Panel, Design AESA Studies
  
- 1989    First NRA (joint R & E), Research Funding
  
- 1990    Ad Hoc Committee on Emissions  
         Ames Workshop on Atmospheric Measurements  
         "White Papers" on HSCT (NASA Ref.Publ.)  
         Second NRA & Research Funding
  
- 1991    First Annual Meeting - Va Beach  
         Committee on Models & Measurements  
         Committee on Aircraft Campaigns  
         Committee on Aerosols, Soot & Particulates



NATIONAL AERONAUTICS  
AND SPACE ADMINISTRATION

August 15, 1990

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NRA-90-OSSA-20

# **Research Announcement**

## **The Atmospheric Effects of Stratospheric Aircraft: Modeling and Measurement in Support of the High-Speed Research Program**

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## NASA Research Announcement

### **THE ATMOSPHERIC EFFECTS OF STRATOSPHERIC AIRCRAFT: MODELING AND MEASUREMENT IN SUPPORT OF THE HIGH-SPEED RESEARCH PROGRAM**

NASA Research Announcement NRA-89-OSSA-16

Released July 1989, Proposals due 31 Oct 89

25 / 42 Proposals accepted

NASA Research Announcement NRA-90-OSSA-20

Aug 1990, Proposals due 1 Nov 90 & 1 May 91

About 35 proposals in each cycle

#### Research Elements of HSRP/AESA Studies:

Engine/Airfleet Emission Scenarios

Aircraft Plume Chemistry and Dispersion

Global Transport and Accumulation of Aircraft Exhaust

Global Chemical Models for Stratospheric Ozone

Aircraft Impacts on Tropospheric Chemistry and Climate

Lab Measurements of Gas and Aerosol Chemistry

Atmospheric Observations and Field Experiments

**NASA  
Reference  
Publication  
1250**

1991

## **The Atmospheric Effects of Stratospheric Aircraft: A Topical Review**

**H. S. Johnston**  
*University of California  
Berkeley, California*

**M. J. Prather and R. T. Watson**  
*NASA Office of Space Science and Applications  
Washington, D.C.*

**NASA**  
National Aeronautics and  
Space Administration  
Office of Management  
Scientific and Technical  
Information Division

1991

## The Atmospheric Effects of Stratospheric Aircraft: A Current Consensus

A. R. Douglass  
*Goddard Space Flight Center*  
*Greenbelt, Maryland*

M. A. Carroll  
*NOAA Aeronomy Laboratory*  
*Boulder, Colorado*

W. B. DeMore  
*Jet Propulsion Laboratory*  
*Pasadena, California*

J. R. Holton  
*University of Washington*  
*Seattle, Washington*

I. S. A. Isaksen  
*Institute of Geophysics*  
*Oslo, Norway*

H. S. Johnston  
*University of California*  
*Berkeley, California*

M. K. W. Ko  
*Atmospheric Environmental Research, Inc.*  
*Cambridge, Massachusetts*

## HSRP/AESA First Program Report

### **The Atmospheric Effects of Stratospheric Aircraft: A First Annual Report (NASA Ref. Publ.)**

Chapter 0. Introduction (Prather & Wesoky)

Chapter 1. Aircraft and Engine Emissions (Miake-Lye)

Chapter 2. Natural Cycles: Gases (Douglass)

Natural Cycles: Aerosols (Turco)

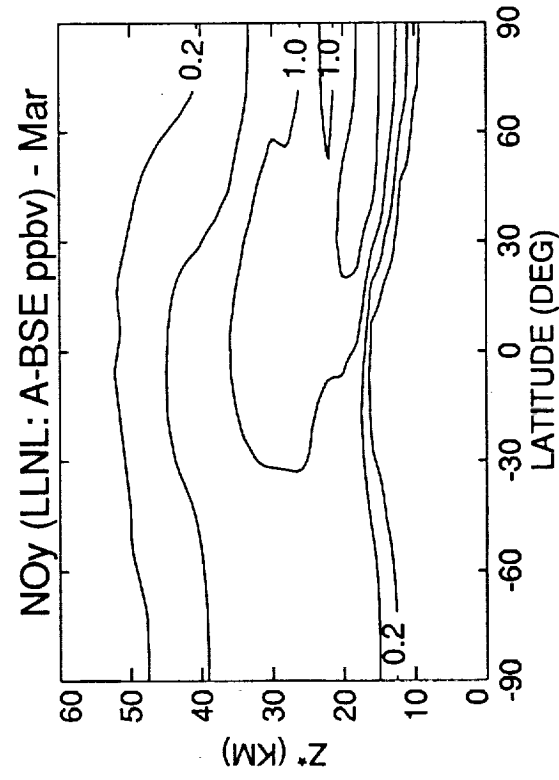
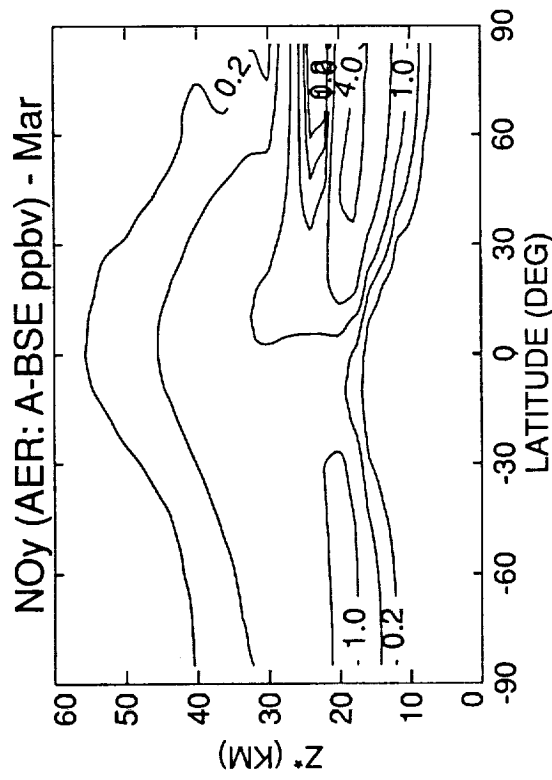
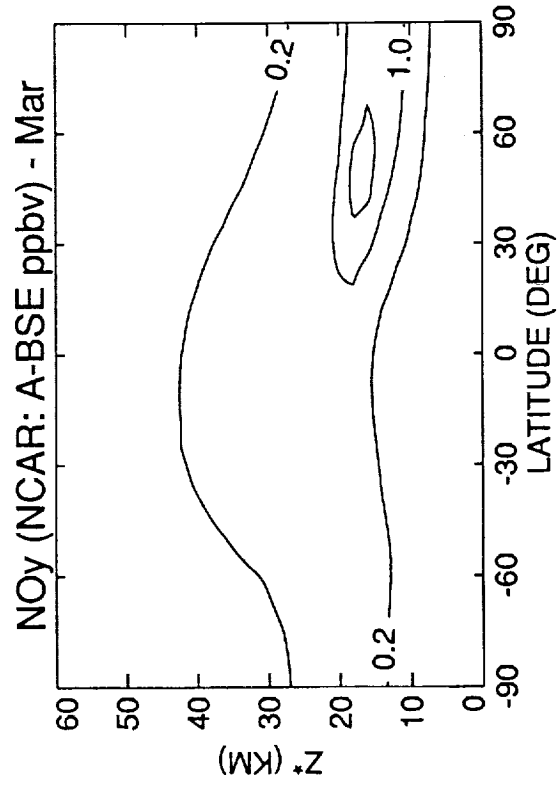
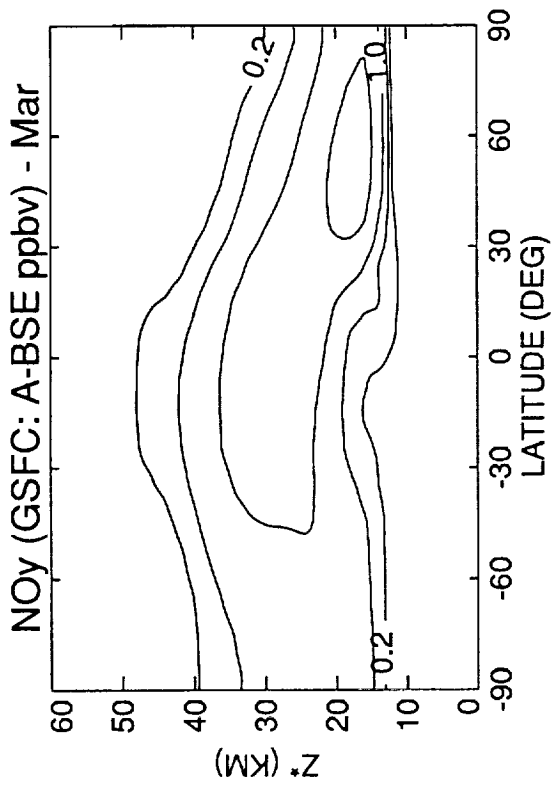
Chapter 3. Scenarios for Future Air Travel (Wuebbles)

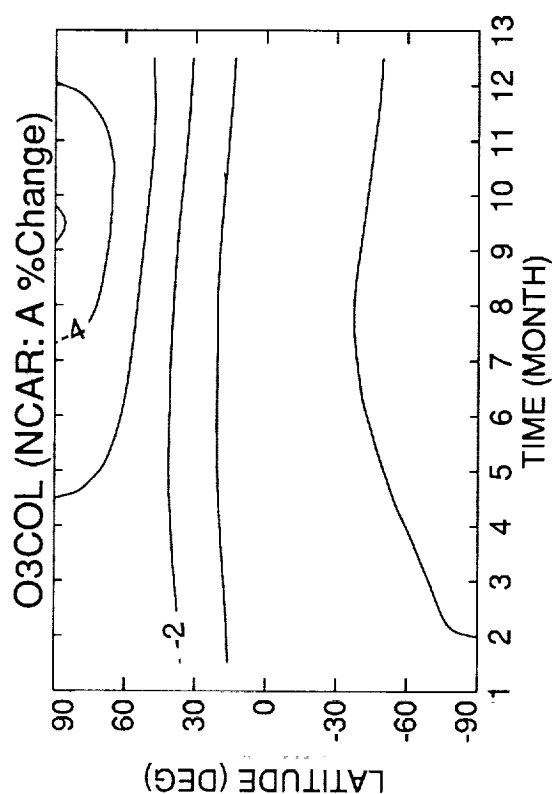
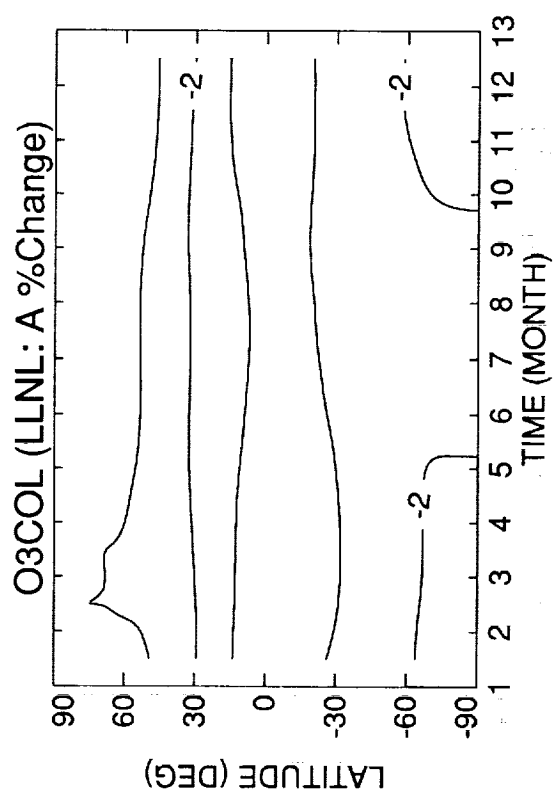
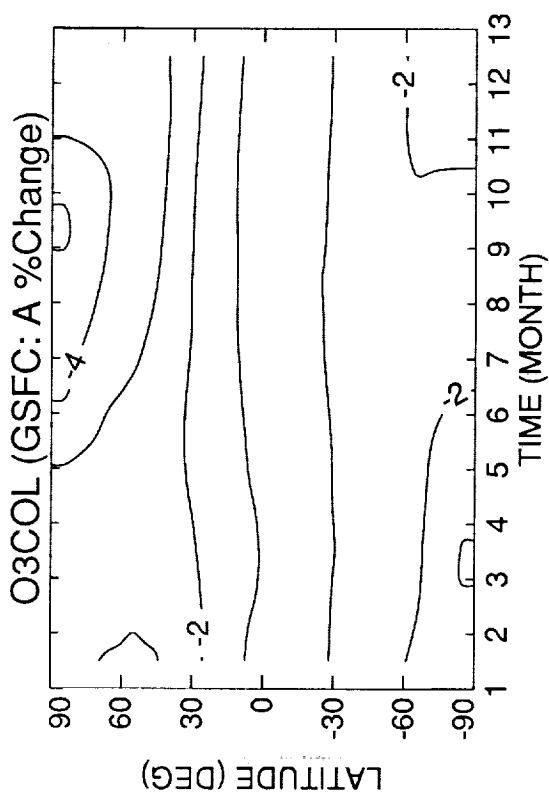
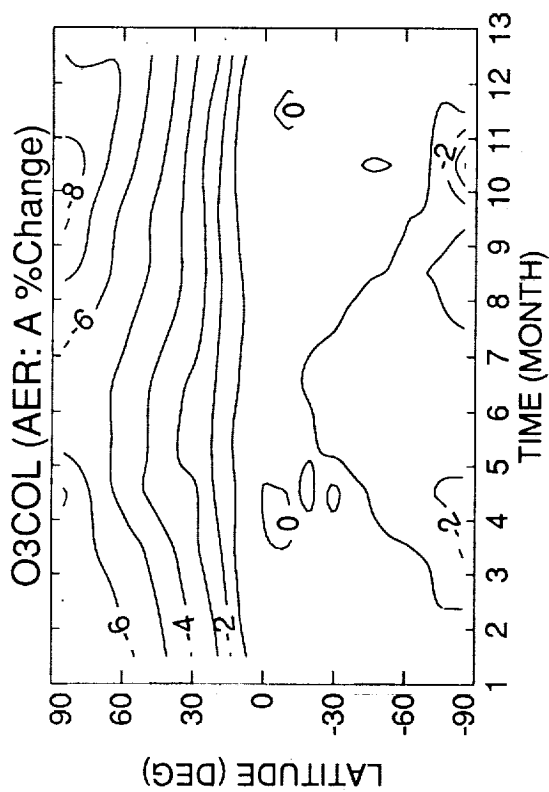
Chapter 4. Sensitivity Studies with 2-D models (Ko)

Chapter 5. Aircraft Campaign Workshop (Schmeltekopf)

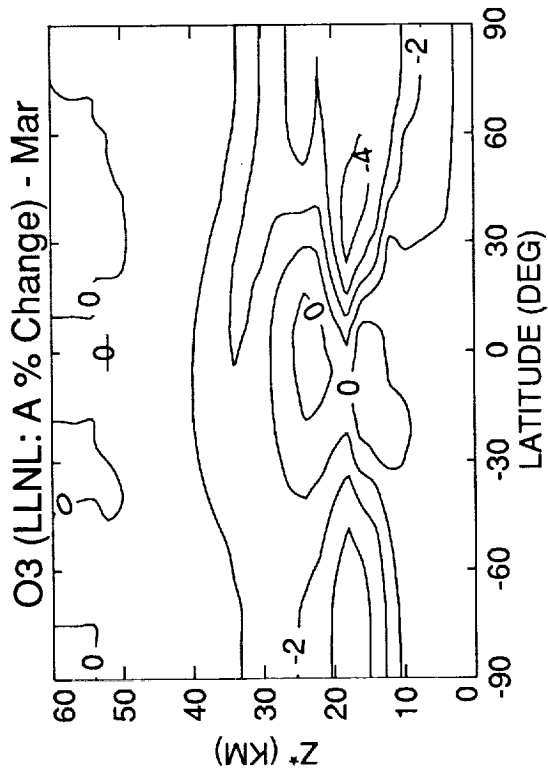
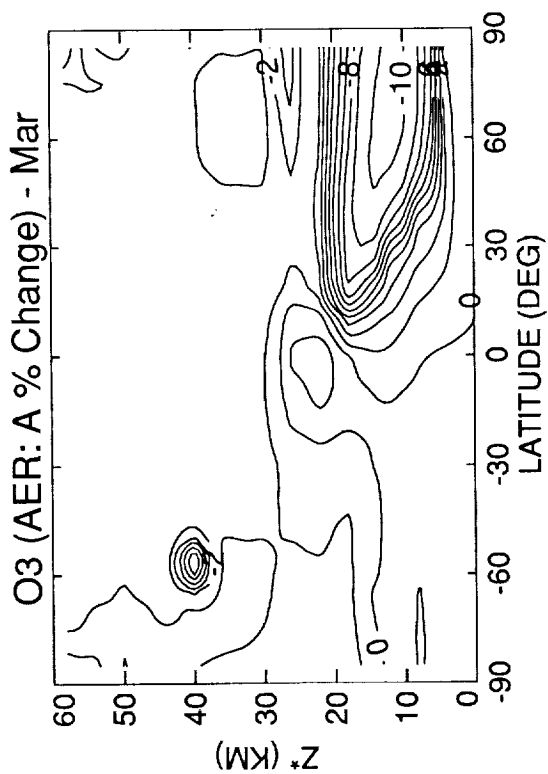
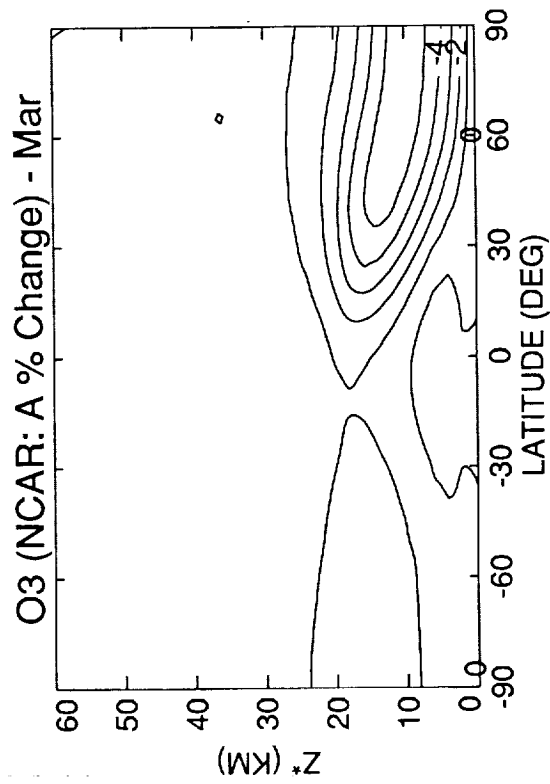
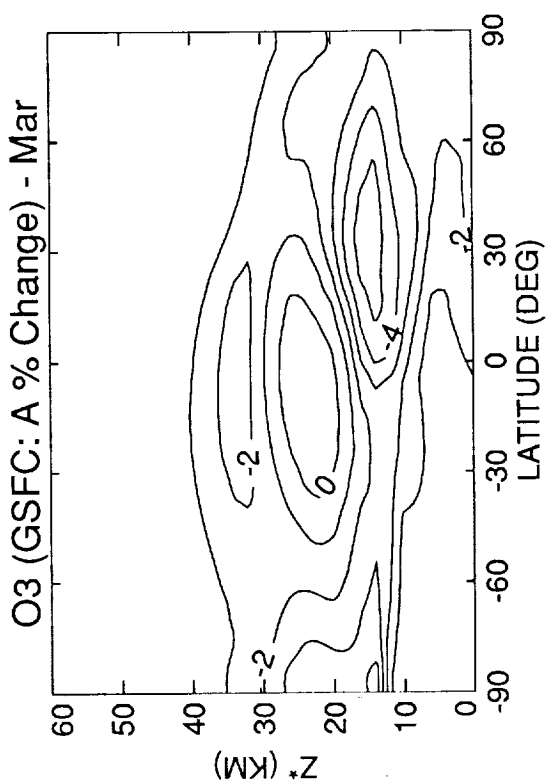
Chapter 6. HSRP/AESA Research Abstracts (PI's)

(External Review Complete)





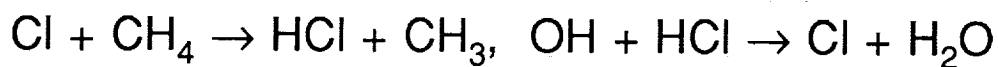
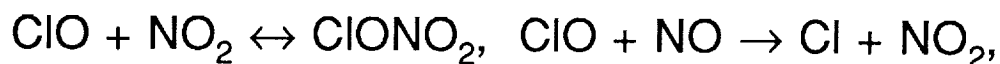




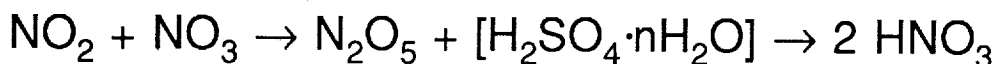
## HSRP/AESA: Complications?

### *Stratospheric Ozone Chemistry*

Chlorine - Nitrogen Interference: ClO destroys O<sub>3</sub>



Heterogeneous Chemistry [sulfate]: NO<sub>2</sub> destroys O<sub>3</sub>



Polar Stratospheric Clouds: HCl & ClONO<sub>2</sub> → ClO

HSCTs enhance PSCs = HNO<sub>3</sub>·3H<sub>2</sub>O, H<sub>2</sub>O ice

## **HSRP/AESA PLANS & MILESTONES**

- 1991    First Annual Report  
          AASE-II Measurement Campaign
  
- 1992    Models & Measurements Comparison  
          SPADE-I Measurement Campaign  
          UNEP-WMO Report on Ozone & CFCs
  
- 1993    Annual Meeting / NAS Review  
          UARP Report to Congress on Ozone
  
- 1994    SPADE-II Measurement Campaign
  
- 1995    Annual Meeting / International Review  
          Report to UNEP-WMO on Ozone

## **HSRP/AESA Aircraft Campaigns**

### **AASE-II: Second Airborne Arctic Stratosphere Expedition**

October 1991 thru March 1992, ER-2 & DC-8 platforms

Primary: Upper Atmos Research Program / OSSA

HSRP additional support for specific objectives:

- Extend chemical tracer observations (latitude & altitude)

- Examine NO<sub>x</sub> & O<sub>3</sub> chemistry as strat-troposphere mix

- Identify possible signature of subsonics in stratosphere

- Opportunity to sample Concorde flight corridor

### **SPADE: Stratospheric Photochemistry, Aerosols & Dynamics Expedition**

September 1992, ER-2 (from Ames) & Balloons (Dryden)

New instruments - NO/NO<sub>y</sub>, CO<sub>2</sub>, OH/HO<sub>2</sub>

Diurnal chemistry - OH, HO<sub>2</sub>, NO, NO<sub>2</sub>, ClO, BrO

Heterogeneous chemistry on sulfate aerosols

NO<sub>x</sub> chemistry in lower stratosphere

A campaign directed at the needs of the High-Speed Research Program

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## **Stratospheric Photochemistry, Aerosols & Dynamics Expedition: SPADE '92**

---

ER-2, September 1992 (4 weeks) out of Ames (Moffett Field)

Radicals & Fast Chemistry:

NO, NO<sub>2</sub>, HNO<sub>3</sub>, HCl, ClO, BrO, OH, HO<sub>2</sub>, O<sub>3</sub>.

Reservoirs & Tracers:

NO<sub>y</sub>, H<sub>2</sub>O, CH<sub>4</sub>, N<sub>2</sub>O, CFCI<sub>3</sub>, CO<sub>2</sub>.

Aerosols & Dynamical Variables:

Aerosol surface, CN, T, pv, winds, clouds

UV-Visible irradiance, in situ and satellite observations

Flights: 12 6-hr flights out of Moffett (MWF for 4 weeks)

Sunrise Diurnal (2) and Sunset Diurnal (2)

Mid-Day with dives for profiling (2)

Latitude to 19 N & dive (1), to 55 N & dive (1)

Reserve (3) and Engineering (1)

---

Balloons, September 1992 (same period) out of Dryden (Edwards AFB)

Light-Weight Packages, if available: NO, NO<sub>y</sub>, N<sub>2</sub>O, ClO, O<sub>3</sub>.

Flights: 2, if possible, to coincide with ER-2 overpasses.

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Meteorological Support

Real-time Forecasts and Satellite Imagery

Trajectories and other Dynamical Analyses

---

Data Analysis and Photochemical Modelling (in field)

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Project Scientist:

Steve Wofsy

Deputy Project Scientist:

Art Schmeltekopf

Project Manager:

Estelle Condon

Program Scientist:

Michael Prather

---

## **HSRP Program-Wide Issues Linked with Assessment:**

Assess Realistic Fleet Emission Scenarios based on the best Engine Emissions, Aircraft Efficiency, Operational Constraints.

Coordinate Scientific Assessment with Optimization of Airframe/Engine Design.

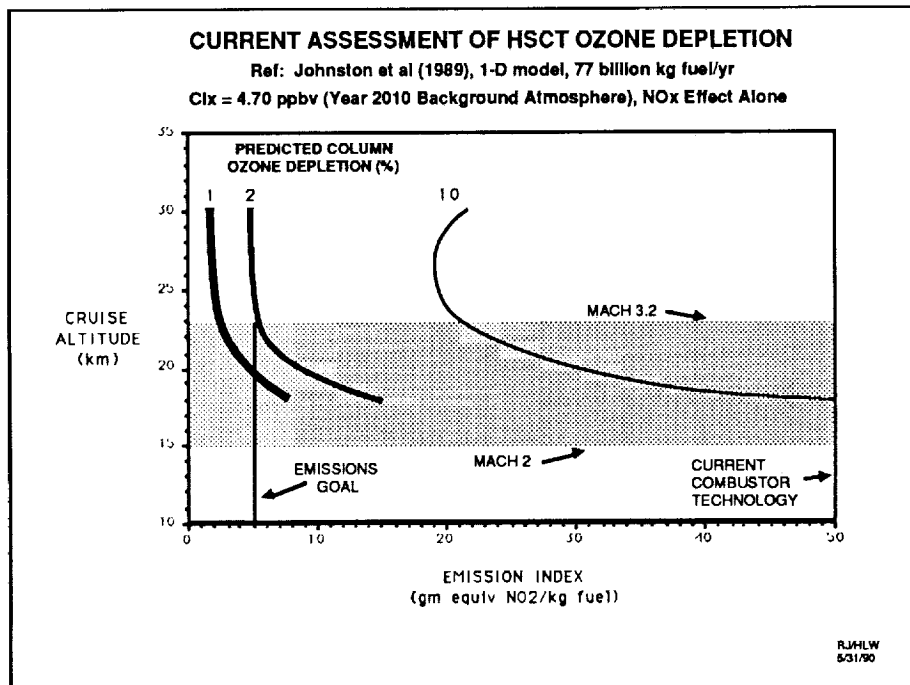
Coordinate Scientific Assessment with National & International Regulatory Agencies.

Define Uncertainties in the Assessment:

- Gas and Aerosol Chemistry
- Future Atmospheric Composition & Climate
- Validation of Global Models

## CURRENT ASSESSMENT OF HSCT OZONE DEPLETION

Although continuing atmospheric studies, as typified by this current 1-D model assessment, are needed to fully understand and quantify the levels of NO<sub>x</sub> emissions that may be acceptable, it is clear that combustion technology development focussed on reducing NO<sub>x</sub> is paramount before U.S. industry could commit to an HSCT development program. Fortunately, prior programs such as those sponsored by NASA and the Department of Energy (i.e., for stationary gas-turbine powerplants) indicate that reduction to levels in the range of 3 to 8 grams of NO<sub>x</sub> per kilogram of fuel is possible with advanced combustor design concepts.



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# **HSR EMISSIONS TECHNOLOGY**

## **STATUS REPORT**

### **1ST ANNUAL HIGH-SPEED WORKSHOP**

**MAY 14, 1991**

**JOHN R. FACEY  
ACTING DEPUTY DIRECTOR  
PROPULSION, POWER & ENERGY DIVISION  
OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY**

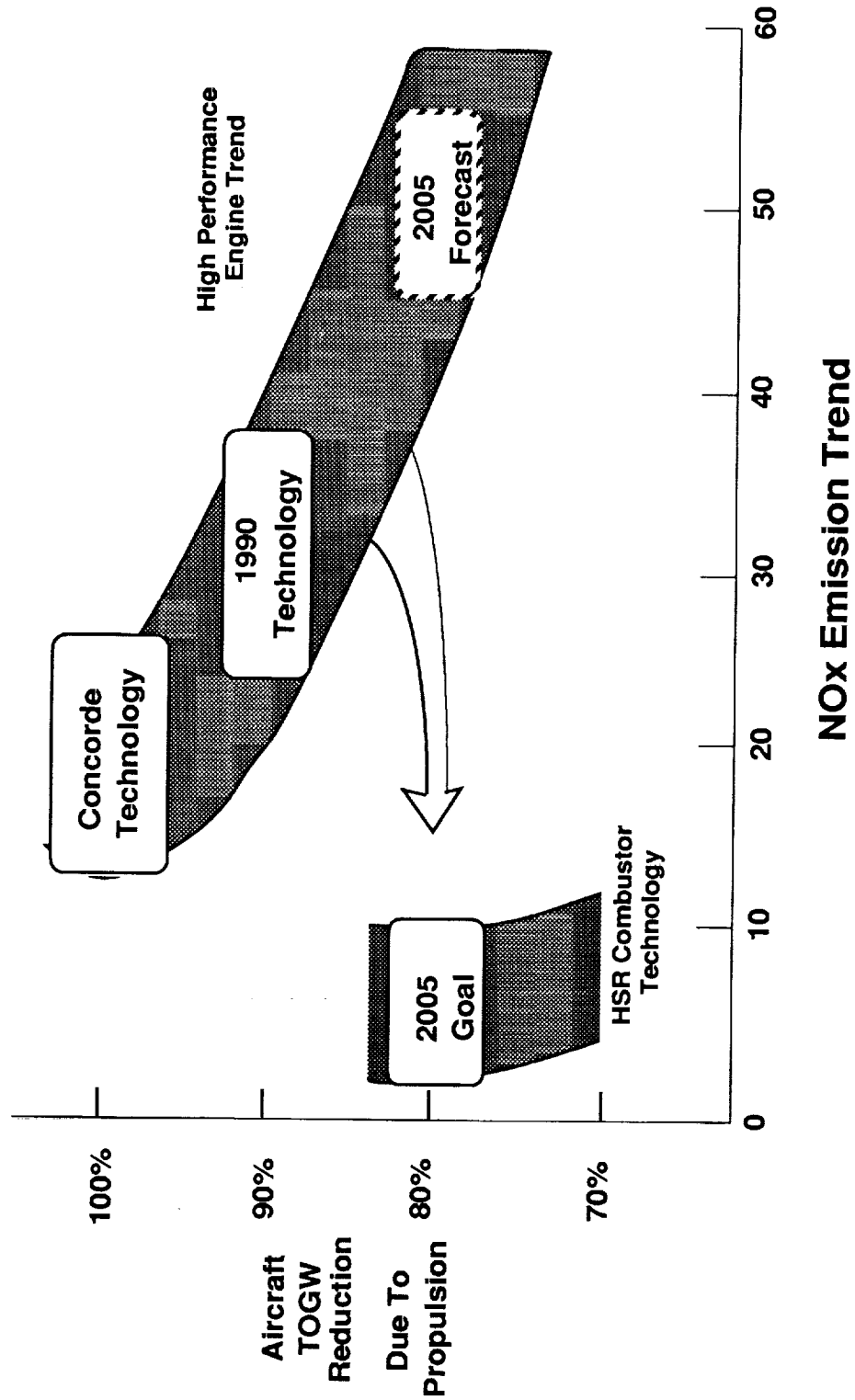
## STATE OF TECHNOLOGY - COMBUSTOR EMISSIONS

The current aircraft production state-of-the-art for establishing High-Speed Civil Transport emissions is based on the technology demonstrated by the Concorde propulsion system. Unfortunately, the requirement for an economically viable high-speed transport will result in an advanced propulsion system that produces increased NOx emissions if it uses current combustion technology. The engine and flight parameters that will cause increased levels of NOx for a system designed for introduction in 2005 versus the Concorde are:

- Increased flight Mach number which results in increased propulsion system temperatures and pressures, in particular, the for the combustor
- Increased engine cycle pressure ratio which will also raise the combustor inlet temperatures and pressures
- Increased engine cycle (combustor exit) temperatures

It is forecast that a economically viable 2005 engine that uses current technology for combustor design will result in a NOx emissions index that is nearly three times as high as the Concorde. Thus it is necessary to develop advanced technology for application in new combustor concepts to attain the goals of the HSR program.

# State of Technology - Combustor Emissions



## ULTRALOW NO<sub>x</sub> COMBUSTOR DESIGN CONCEPTS

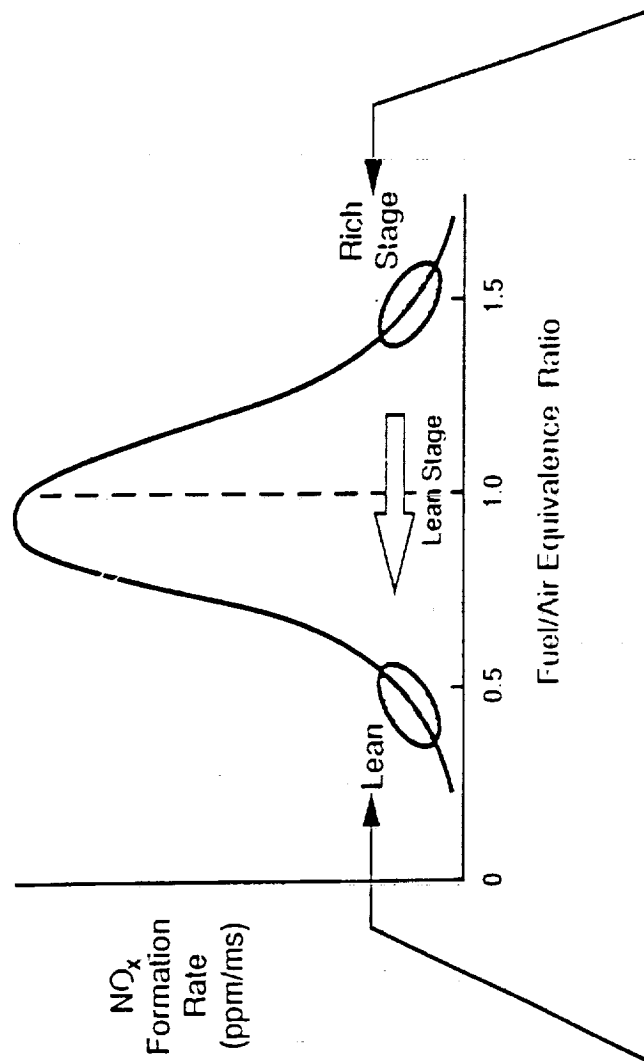
The amount of NO<sub>x</sub> produced by a gas turbine combustor is a function of a number of parameters in the combustion process:

- Increased maximum temperature in combustion zone yields more NO<sub>x</sub>
- Increased combustor inlet temperature yields higher NO<sub>x</sub>
- Longer residence time at maximum gas temperature yields more NO<sub>x</sub>
- Higher combustor pressure level yields more NO<sub>x</sub> (relatively weak function)

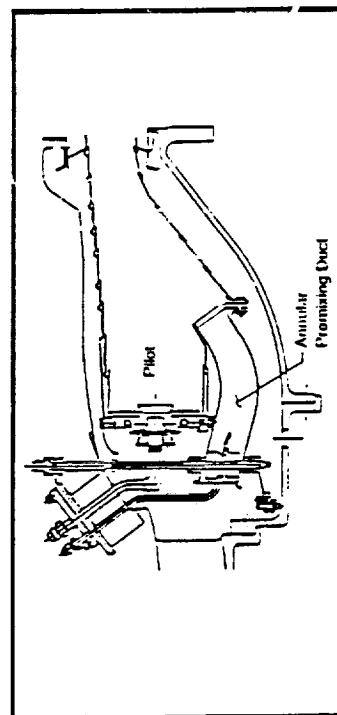
Compared to current operational combustors, the HSR combustor will operate at increased inlet and exit temperatures as well as higher pressures. Thus the only parameters available to us for control of the production of NO<sub>x</sub> are the maximum temperature in the combustion zone and the residence time at the maximum temperature. The combustion zone temperature is controlled by operating at the minimum fuel/air equivalence ratio (lean) required to attain the desired turbine inlet temperature. While simple in concept, practical application of the lean approach to a combustor may be difficult because of the problem of attaining uniform fuel/air mixing without undesirable effects such as flashback. Thus, a second concept is being considered that uses a rich burn portion of the combustor, which reduces the need for perfect mixing of the raw fuel with the air, to convert the fuel into gaseous products followed by a rapid mixing of the combustion gases and the remaining combustion air prior to completing the combustion process at the same lean equivalence ratio as the lean burn concept. Each of these concepts are intended to maintain the maximum temperature below the level that results in rapid NO<sub>x</sub> formation.

Each of these concepts must also be implemented so that that highest temperature is maintained for very short periods. Thus, they must be as short in length as possible.

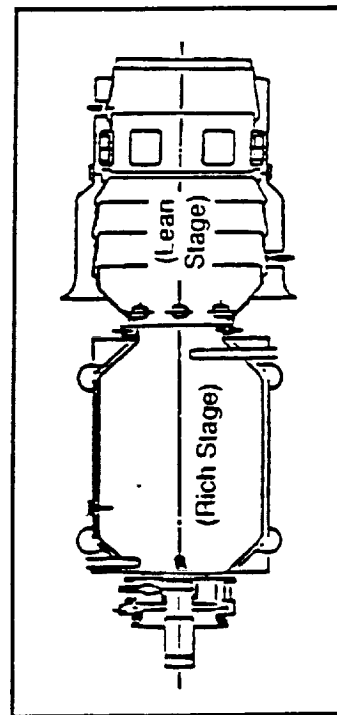
# Ultralow $\text{NO}_x$ Combustor Design Concepts



Lean Premixed/Prevaporized



Rich/Quick Quench/Lean



## EMISSIONS PROGRAM KEY MILESTONES

The approach to emissions reduction technology development couples analytical and experimental efforts in a process that first builds a strong fundamental foundation, and then applies that knowledge base to engine-level combustor hardware for rig verification tests:

- Early in the program analysis codes are being used to assess proposed concepts and configurations to identify and support laboratory-level experiments. Advancements in detailed computational analysis are providing increasingly better insight to complex flow processes at the controlling physics level. The experimental testing, including rapid fuel vaporization and fuel-air mixing, rich- and lean-fuel combustion chemical kinetics, flashback criteria and avoidance, is defining key design factors that must be achieved at both the subcomponent and full combustor hardware level. NOx destruction additives were to be a part of the experimental program, but, to date, no additives studied analytically have resulted in a significant reduction in NOx under lean conditions with acceptable residence times and/or environment impact. If a good additive is discovered, it will be tested at a later date.
- Development of low-emission combustor technology will then proceed in a building block manner beginning with key subcomponents such as the fuel injector and fuel-air mixing devices. Once all subcomponent requirements are individually achieved, they will be integrated into practical sector and full combustor designs in a series of development tests over the complete range of simulated operating conditions.

Significant university and U.S. industry participation with the NASA research centers is an integral part of this approach to insure all available expertise and facilities are applied in solving this difficult and critical challenge.

**EMISSIONS PROGRAM KEY MILESTONES**

<b>FY 1991</b>	<b>FLAMETUBE TESTING OF BOTH LEAN/PRE-MIXED/ PREVAPORIZED &amp; RICH-BURN/QUICK-QUENCH/ LEAN-BURN CONCEPTS</b>
<b>FY 1992</b>	<b>LABORATORY COMBUSTION DATA BASE COMPLETED</b>
<b>FY 1993</b>	<b>CODE UPDATE BASED ON LABORATORY DATA BASE AND SUB-COMPONENT TECHNOLOGY DATA BASE</b>
<b>FY 1994</b>	<b>INITIATE COMBUSTOR RIG TESTING</b>
<b>FY 1995</b>	<b>VERIFICATION OF 3-8 EMISSIONS INDEX IN PRACTICAL COMBUSTOR CONFIGURATION</b>

## HSR SQUARE FLAME TUBE RIG LEAN PREMIXED/PREVAPOORIZED COMBUSTION (LPP)

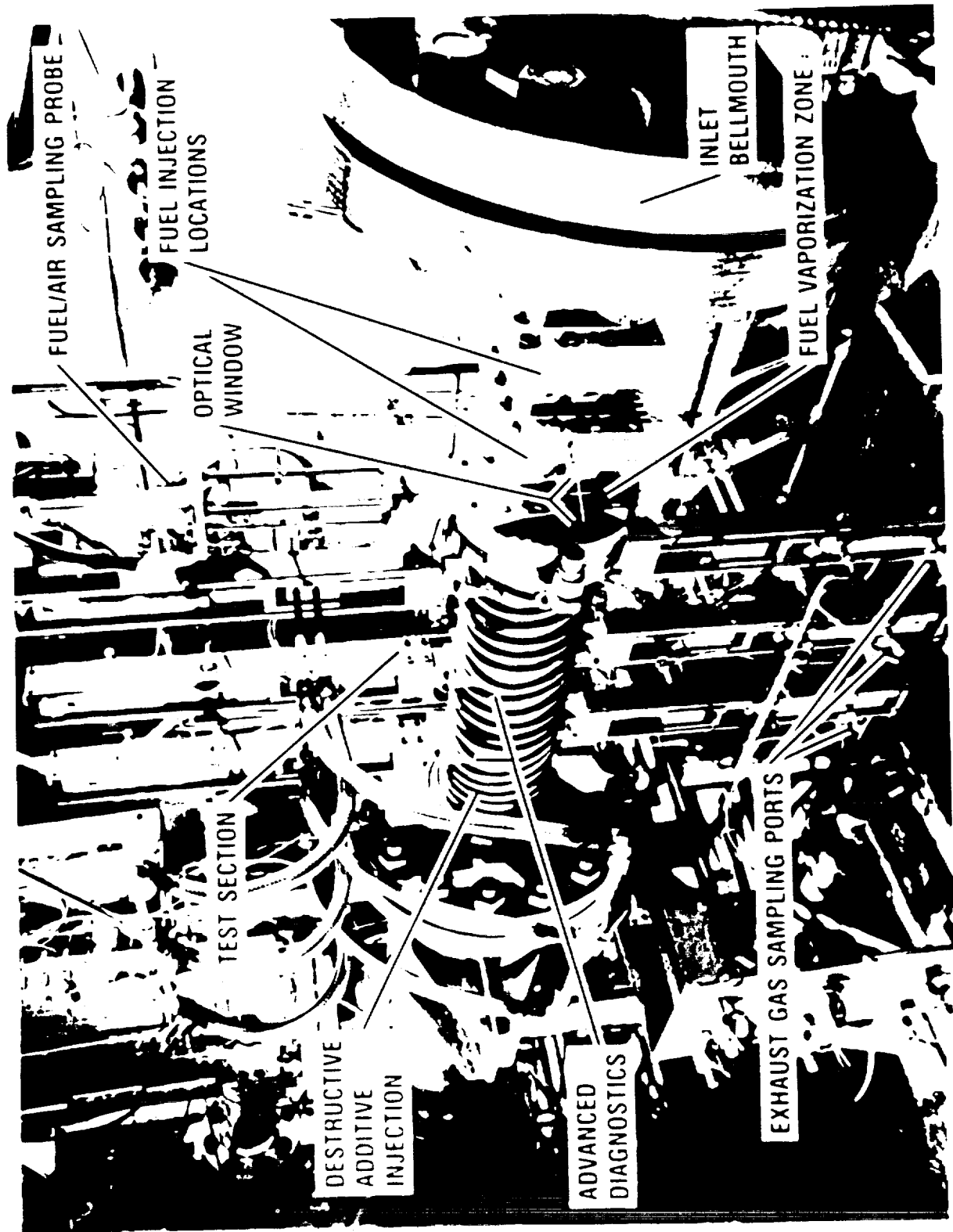
The laboratory environment for controlled research and concept technology development using advanced diagnostics is provided by the Lewis Research Center's flame tube facility. It provides a

- wide-range of preconditioned inlet air temperature, pressure, and humidity
- high-accuracy measurement of fuel and airflow rates
- fuel droplet size; laser velocimetry; Schlieren photography; and laser induced fluorescence measurements; and
- combustion products gas sampling probes at three axial locations.

A "parallel - dual leg" capability provides flexibility and concurrent testing of alternate concept configurations. A lean premixed prevaporized configuration has been evaluated during the last year, and a rich-burn / quick-quench / lean-burn configuration has now been installed in the second leg of the facility.



# HSR SQUARE FLAME TUBE RIG LEAN PREMIXED/PREVAPOORIZED COMBUSTION (LPP)



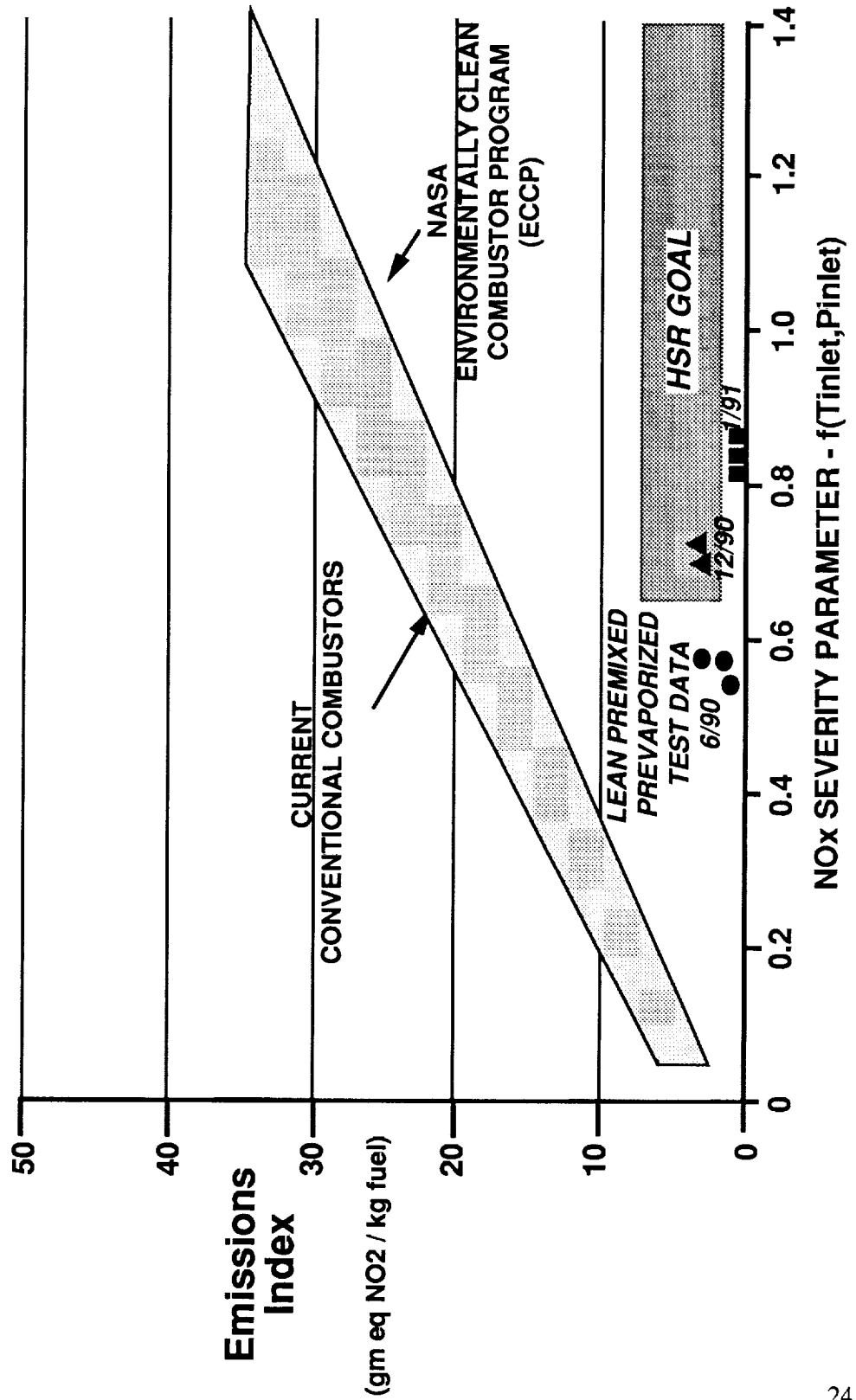
## LEAN PREMIXED PREVAPORIZED (LPP) FLAMETUBE RESULTS

Emission indices better than the HSRP goal level of 5 grams equivalent  $\text{NO}_2$ /kilogram fuel have been demonstrated in the Lewis flametube facility, and are very encouraging relative to the predicted ozone depletions presented earlier. Very good results have been obtained with plain jet injectors at lower severity factors and with multiple venturi injectors at higher severity factors. The most recent LPP results were obtained at a severity factor near 1.0 with emission indices remaining below 3g/kg. The rich-burn/quick-quench/lean-burn flame tube rig has been checked out at cold flow conditions and LeRC is expected to begin burning tests this week. NASA expects to have completed the flame tube experiments by the end of FY 1991 that will establish the technology capability and critical factors for achieving a 3-8 emissions index at simulated supersonic cruise conditions.

These early results are nearly an order of magnitude below current stoichiometric primary-zone combustors used in modern high-bypass engines. However, considerable effort will be required to integrate the laboratory concept into a practical engine configuration. Planned additional testing will include extensive mapping of the severe HSRP goal environment and development of a sensitivity database (e.g., fuel-air mixing) for code validation and updating prior to the selection of combustor concepts at the end of FY 1992 for development of a combustor rig for validation of the HSR emission goals in FY 1995.

# HIGH-SPEED RESEARCH PROGRAM EMISSIONS REDUCTION

## LEAN PREMIXED PREVAPORIZED FLAMETUBE RESULTS



## EMISSIONS STANDARDS

Emissions standards will be critical to the development of HSCT aircraft, but currently exist for no aircraft at cruise altitudes. The regulatory process will probably be based on existing EPA authority under the Clean Air Act, and involve broad government and industry cooperation in preparing an environmental impact statement. By 1993, HSRP progress should serve as a basis for a national assessment of potential HSCT atmospheric impact. Because of the global implications of atmospheric pollution, it is expected that the U.N.'s International Civil Aviation Organization (ICAO), through its Committee on Aviation Environmental Protection, will play a major role in establishing standards.

### EMISSIONS STANDARDS

- **ATMOSPHERIC IMPACT OF HSCT FLEET CURRENTLY UNCERTAIN, BUT ASSESSMENT UNDERWAY**
  - CHEMISTRY & DYNAMICS MODELS
  - MEASUREMENTS TO CALIBRATE & TEST MODELS
  - GLOBAL CHANGE ISSUES
- **EMISSIONS STANDARDS DEFINITION CRITICAL TO HSCT PROGRESS**
- **REGULATORY PROCESS FOR CRUISE EMISSIONS NOT ESTABLISHED**
  - CLEAN AIR ACT ALLOWS EPA ADMINISTRATOR TO ASSESS IMPACT
  - ENVIRONMENTAL IMPACT STATEMENT INVOLVING EPA, FAA, NASA AND INDUSTRY WILL PROBABLY PRECEDE REGULATION
- **1993 NATIONAL INTERAGENCY ASSESSMENT PROPOSED**
  - AESA ADVISORY PANEL ASSESSMENT IS PRECURSOR
  - CHARTER NOW BEING CONSIDERED
- **1995 INTERNATIONAL ASSESSMENT FINAL PROPOSED HSRP ACTION**
  - POLITICALLY ESSENTIAL FOR HSCT ECONOMIC SUCCESS
  - LIKELY TO INVOLVE INTERNATIONAL CIVIL AVIATION ORGANIZATION

## NOISE STANDARDS

The regulatory situation for community noise is somewhat clearer than for emissions. Federal Aviation Regulations Part 36 (FAR 36), Stage 3 provides current noise rules for subsonic aircraft, and is expected to serve as the basis for HSCT constraints. In May 1990, the FAA issued a Notice of Proposed Rulemaking that suggested that FAR 36, Stage 3 be applied to future civil supersonic aircraft. Although NASA and other organizations which commented on this proposal agree with the spirit of the rule, it was suggested that certification procedures should allow for advanced technology such as computer controlled flap and throttle settings. Also, because of the character of noise from proposed HSCT engines, it was suggested by NASA and others that the procedure be more flexible in terms of noise trades between FAR 36 measuring stations. Such trades might result in higher than currently allowed noise on airport grounds, but lower noise in the surrounding community.

It now appears that the FAA, in recognition of the developing status of technology, will delay noise rule making. It also appears that, as for emissions, considerable international coordination will be required for establishment of HSCT noise standards.

### NOISE STANDARDS

- **CURRENTLY NO STANDARDS FOR CIVIL SUPERSONIC AIRCRAFT**
- **FAA MAY 1990 NOTICE OF PROPOSED RULEMAKING SUGGESTED SAME FAR 36, STAGE 3 STANDARDS AS FOR SUBSONIC AIRCRAFT**
- **NASA NOV 1990 COMMENTS SIMILAR TO OTHER RESPONSES**
  - NOISE IMPACT ON COMMUNITY SHOULD BE NO GREATER THAN PRODUCED BY SUBSONIC AIRCRAFT CERTIFIED UNDER STAGE 3
  - HSCT CERTIFICATION RULE SHOULD ALLOW ADVANCED FLIGHT PROCEDURES
  - COMPLIANCE DEMONSTRATION SHOULD BE FLEXIBLE IN TERMS OF NOISE TRADES BETWEEN MEASURING STATION
  - RULEMAKING SHOULD INVOLVE INTERNATIONAL COORDINATION
- **FAA NOW LIKELY TO DELAY RULE**

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# **HSR SOURCE NOISE TECHNOLOGY**

## **STATUS REPORT**

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**MAY 14, 1991**

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## HSCT COMMUNITY NOISE TECHNOLOGY CHALLENGE

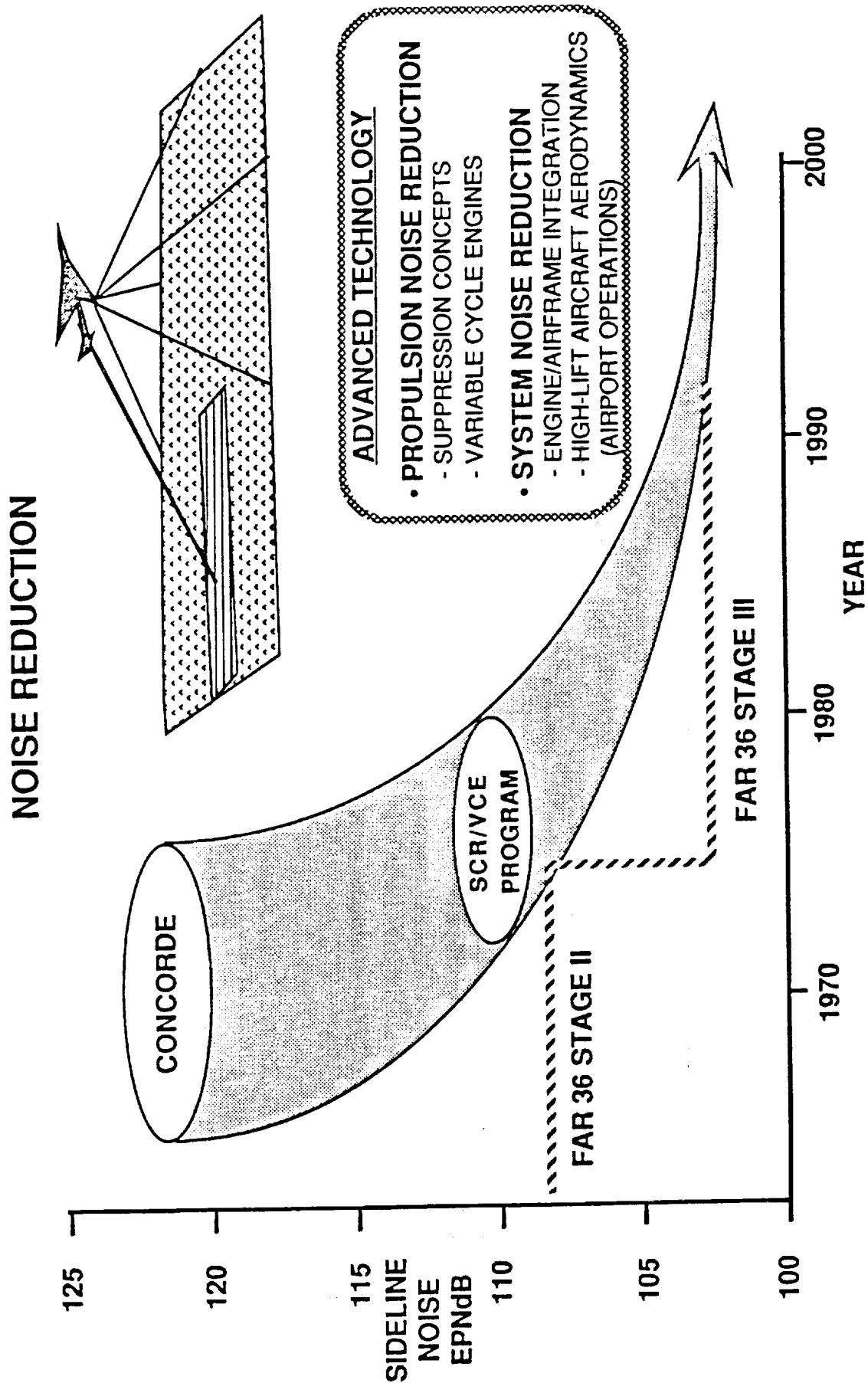
Aircraft noise is a subject of significant public concern. This has led to legislation aimed at ensuring noise levels in the airport community meet stringent requirements as set forth in Federal Aviation Regulation, Part 36 (FAR 36). Currently Stage III noise levels are in effect for subsonic aircraft certified after 1975, and have recently been proposed by the FAA as appropriate for supersonic aircraft. The technical challenge is to achieve major jet noise suppression without significant performance and economic penalty.

An estimate of the amount of noise suppression required can be obtained by considering a future commercial transport having a takeoff gross weight of 750,000 lbs., powered by four turbojet engines with 50,000 lbs. thrust. Predicted unsuppressed jet noise for this aircraft at the critical FAR 36 sideline measuring station is 121 EPNdB, which exceeds Stage III requirements by 18.5 dB. Hence, considerable noise reduction is needed to meet this challenge.

To put the challenge in perspective, the SCRVCE programs of the late 1970's/early 1980's were only able to achieve approximately one half of the required suppression for Stage III compliance. Thus the advanced technology required for noise reduction will need to consider new suppression, advanced cycles, engine/airframe integration and high-lift aircraft aerodynamics technologies.



# HIGH-SPEED RESEARCH PROGRAM

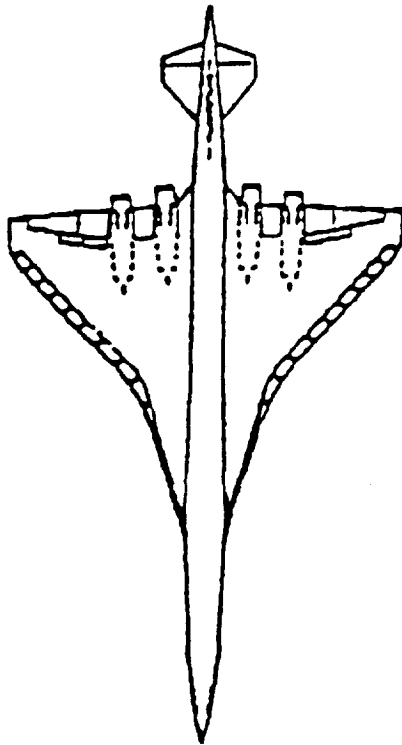


## MEETING HSCT COMMUNITY NOISE CHALLENGE A SYSTEM APPROACH

The noise heard by an observer on the ground or received by a microphone measuring station (i.e., such as defined in FAR 36, Stage 3) is a function of the aircraft propulsion source noise levels, the aircraft flight path and the characteristics of the atmosphere. Therefore, in addition to jet noise suppression, advanced aircraft operating procedures may be utilized to achieve low noise levels on the ground. A system approach utilizing all these elements has been defined for the HSRP.

Novel engine concepts with effective noise suppression devices will first be developed to reduce noise at its source. Efficient aerodynamic high-lift concepts will be utilized to reduce takeoff thrust requirements, and hence reduce noise further. Upgraded system noise prediction codes with improved jet noise suppression modules and atmospheric propagation modules will be exercised with advanced aircraft operating procedures to ensure low noise integrated vehicle systems.

# HSCT COMMUNITY NOISE TECHNOLOGY Challenge



(4) Engines  
TOGW = 750,000 #'s  
Net engine thrust T = 50,000 #'s  
Engine airflow W = 582 #'s/sec  
Engine exhaust velocity  $V = T/W$   
= 2800 ft/sec

	SIDELINE (1500' SL/1000' Alt)	CUTBACK (1500' Alt)
Predicted jet noise (unsuppressed)	121 EPN dB	118 EPN dB (W=599, T=35000)
FAR 36/Stage 3	102.5 EPN dB	105.3 EPN dB
<u>Required suppression</u>	18.5 EPN dB	12.7 EPN dB

## SOURCE NOISE REDUCTION KEY MILESTONES

The approach to source noise reduction technology brings together analytical, fundamental experimental and concept development research efforts in a process that is building a strong fundamental foundation, and applying that knowledge base to advanced concepts for evaluation in scale-model size both without and with forward flight effects before selection of concepts for part-scale verification of performance and noise goals.

- Early in the program a number of advanced concepts are being evaluated both experimentally and analytically while the fundamental experimental data base is being developed. Advanced analytical techniques are being used to guide development and analyze experimental results of advanced concepts such as ejectors designed for maximum secondary air entrainment for noise reduction. The fundamental experiments will be used to help guide the development of improved analytical techniques, verify existing ones, and provide a data base for design of improved noise reduction concepts.
- Facility improvements are also underway. At the Lewis Research Center, the jet exit rig developed for NASP (National Aerospace Plane) nozzle testing has been checked out, and with a new rectangular-to-round transition section that has been recently fabricated, will be used in a number facilities including the 40x80 wind tunnel at Ames Research Center to evaluate part-scale nozzle concepts for noise reduction. Also, Langley Research Center is in the process of adding forward flight capability to the Jet Noise Lab for fundamental noise experiments.
- As part of the current learning process, a review of progress and needs with the industry resulted in the addition of research for acoustic liners to the HSRP Phase I program as well as a second look at scaling of the model results, especially for suppression liners, and an evaluation of the effects of integration with the airframe on noise suppression.

High levels of university and U. S. industry participation with the NASA research centers is an integral part of the program to ensure maximum use of available expertise and facilities for solving a difficult and critical challenge for high-speed civil transports.

**SOURCE NOISE PROGRAM KEY MILESTONES**

<b>FY 1991</b>	<b>FUNDAMENTAL ACOUSTIC EXPERIMENTAL DATA BASE AND EARLY CONCEPT ASSESSMENT/SCREENING</b>
<b>FY 1992</b>	<b>COMPLETE SCREENING OF CANDIDATE CONCEPTS AT SCALE-MODEL SIZE INCLUDING FORWARD FLIGHT EFFECTS - INITIAL FAR 36 STAGE III ASSESSMENT</b>
<b>FY 1993</b>	<b>COMPLETE FUNDAMENTAL ACOUSTIC DATA BASE AND UPDATE ANALYTICAL CAPABILITY</b>
<b>FY 1994</b>	<b>DEFINE ENGINE CYCLES/NOZZLES FOR PART-SCALE EXPERIMENTAL EVALUATION</b>
<b>FY 1995</b>	<b>PART-SCALE COMPONENT TESTS, WITH AND WITHOUT FORWARD FLIGHT EFFECTS TO VERIFY PERFORMANCE AND NOISE LEVELS</b>

## RAPID MIXING TECHNOLOGY

An example of the fundamental noise reduction research activities at Langley Research Center is an effort to study enhanced mixing of supersonic jets with the surrounding atmosphere and thus lower the emitted noise for a given thrust level. It had previously been demonstrated that rectangular jet exit geometry radiates less noise energy than round nozzles for equivalent thrust. Unfortunately for rectangular configurations it is impossible to separate enhanced mixing introduced by asymmetric flow produced by plume shocks from that introduced by asymmetric turbulent flow structure. However, it has been possible to design a low aspect ratio,  $AR=2$ , elliptic nozzle that produces shock-free flow for evaluation of asymmetric turbulent flow.

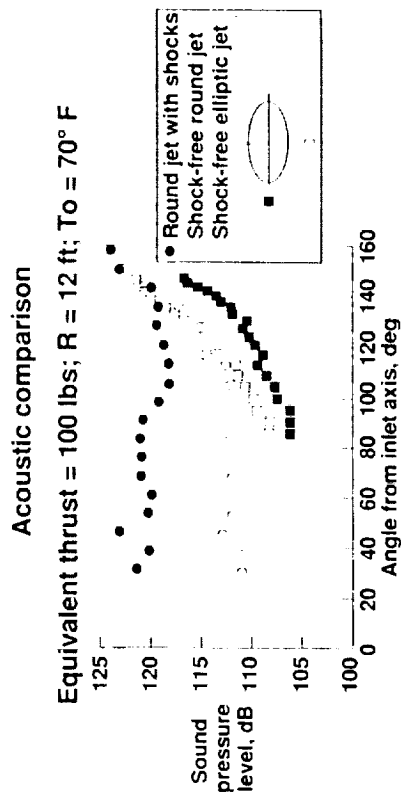
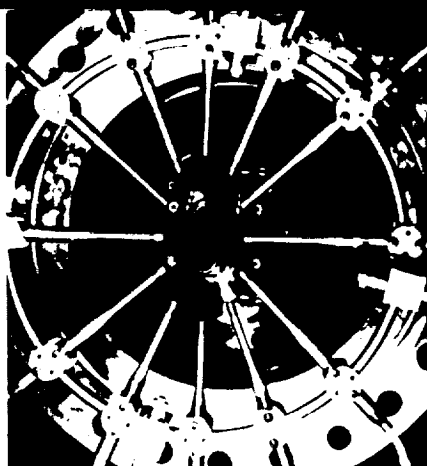
A comparison of round jets with shocks, a shock-free round jet and a shock-free elliptic jet shows that the shock-free round jet produces about 10 dB less noise for sideline at  $90^\circ$  than a round jet with shocks. The elliptic jet produces different levels of noise along the major and minor axes. Compared to shock-containing round jet, the elliptic nozzle provides a sideline reduction of 15 dB at  $90^\circ$  and 5 dB at  $140^\circ$  for the major axis. The results for the minor axis show a minor improvement of 3 dB relative to the shock-free nozzle at  $90^\circ$ . Along the major axis there is a large growth in the momentum thickness due to enhanced vortex entrainment resulting in significant noise reduction.

For the future, fundamental noise research is continuing with the development of a tri-axial elliptic nozzle test bed and the development of the associated theoretical analysis. Other fundamental jet noise experiments include the study of supersonic instability waves, hot generic nozzles, mixed dual flow nozzles, and single flow plug nozzles with and without porosity.

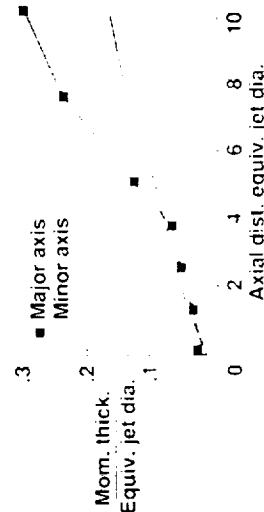
# RAPID MIXING TECHNOLOGY AND THE SUPERSONIC ELLIPTIC NOZZLE

## Part I: Noise reduction

Mach 1.5 elliptic nozzle



Momentum thickness growth



## MIXER/EJECTOR NOZZLES

A number of mixer/ejector nozzle concepts have been designed and experimentally evaluated since the initiation of the HSRP program in 1989. The first was a Boeing concept, a 1970s-era naturally aspirated co-annular (NACA) nozzle modified to achieve enhanced ejector pumping by small high-pressure turbine bypass air tubes placed in the ejector airstream. The concept also used an inverted velocity profile (IVP) with the simulated hot engine exhaust gases fed to the outer stream and the cold ejector air fed to the inner stream. The overall configuration objective was to use the ejector to increase engine airflow while producing a lower mixed jet velocity, and hence lower noise. An experimental evaluation of the NACA nozzle was conducted jointly by Boeing and Langley in the summer of 1989 at the Boeing Low Speed Aeroacoustic Facility. While a noise reduction of 10 EPNdB was achieved relative to round convergent nozzles of similar thrust, the NACA nozzle results were still 10 EPNdB above FAR 36, Stage III requirements.

Although the Stage III goal was not met by the NACA nozzle, it showed that nozzle concepts which augment and mix the engine exhaust with ambient air hold promise for meeting noise goals by providing increased airflow and decreased jet velocity.

New mixer/ejector nozzle concepts, as proposed by Pratt & Whitney (shown) and Boeing, have resulted in increased noise reduction, and have demonstrated secondary ejector flows 120 percent of the primary propulsion system flow, a condition necessary to achieve the desired noise goal.





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## PROMISE OF MIXER/EJECTOR FOR MEETING FAR 36, STAGE III GOAL

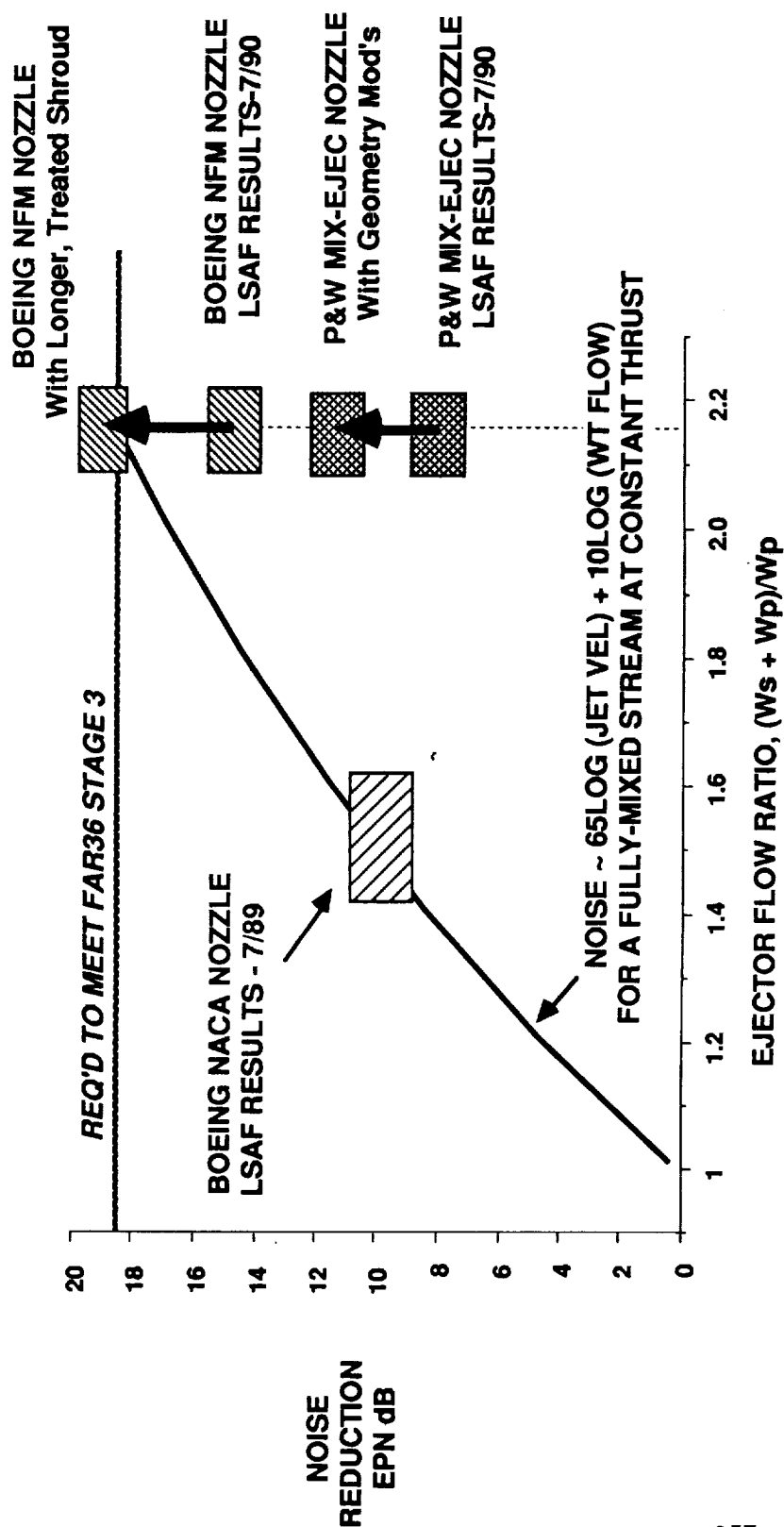
256

Mixer/ejector nozzle concepts are of high interest as a low noise concept because noise is a much weaker function of exhaust weight flow (i.e., 10 log weight flow) than jet velocity (i.e., 65 log jet velocity), thus achieving the desired thrust by higher weight flow rather than high jet velocity which results in a considerable noise benefit.

Both the Pratt & Whitney and Boeing mixer/ejector nozzle concepts have resulted in increased noise reduction at demonstrated high secondary ejector flows (Ws), 120 percent of the primary propulsion system flow (Wp), a condition necessary to achieve the desired noise goal. Continued efforts are still required to enhance mixing of the primary engine exhaust with the ejector flow for improved noise reduction since the particular configuration that achieved the objective noise level utilized a very long, acoustically treated ejector shroud that reduced nozzle performance more than desired. The results to date do, however, show considerable promise that a combination of improved mixing with acoustic treatment could yield a nozzle configuration with the desired level of aerodynamic performance and noise reduction.

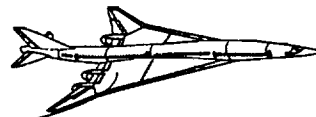
The next series of source noise reduction tests will be conducted this summer in a Lewis wind tunnel with Pratt & Whitney nozzles which will include a see-through window for internal flow diagnostic studies. Other industry concepts include the General Electric 2D suppressor/ejector and the fluid shield nozzle concepts for high flow engine cycles which will be tested in the General Electric acoustic facility starting in mid-1991.

### MIXER-EJECTOR NOZZLE DEVELOPMENT PROGRESS



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# **HSR COMMUNITY NOISE REDUCTION TECHNOLOGY**



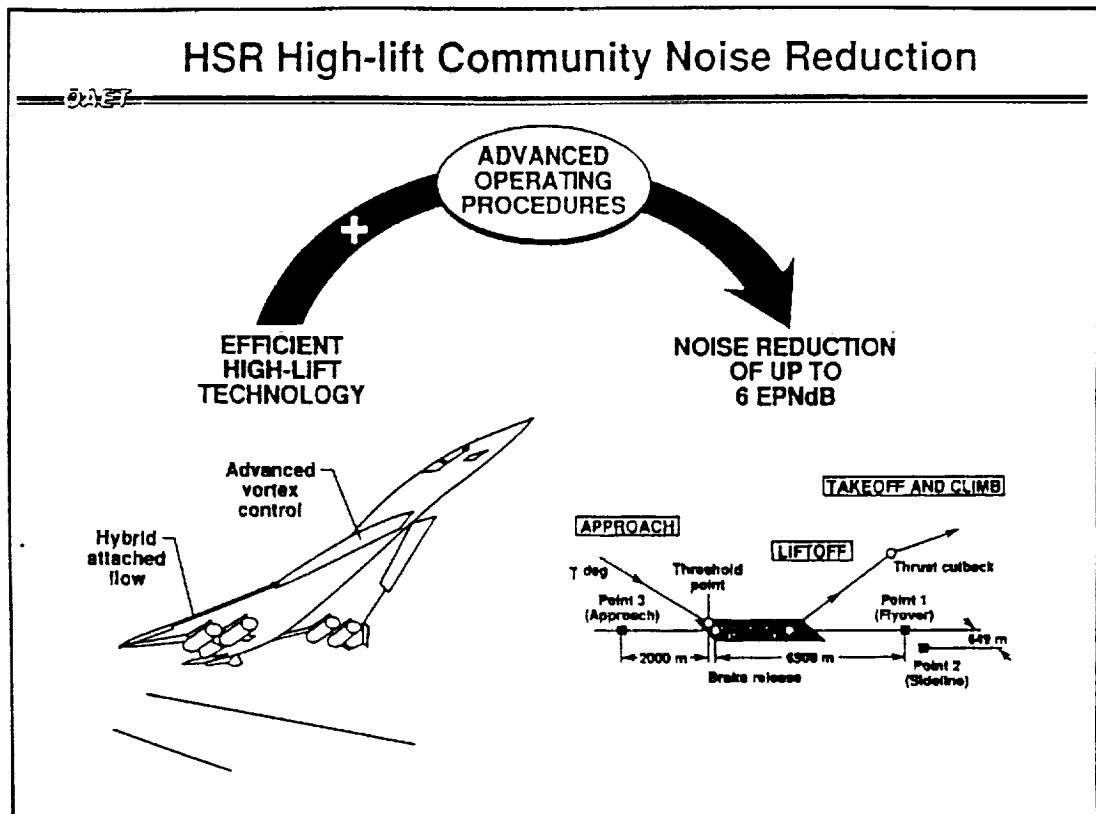
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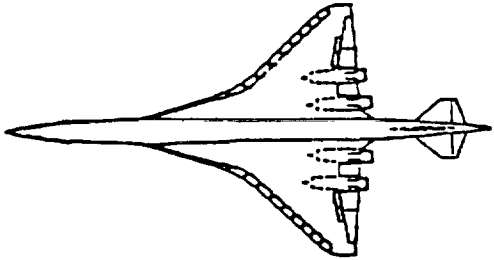
**GEORGE UNGER  
MANAGER, VEHICLE AERODYNAMICS  
AERODYNAMICS DIVISION  
OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY**

**1. This area covers the aerodynamics aspects of meeting the Stage III noise rule including the aeroacoustic prediction of system noise, operating procedures for abatement and high lift devices for more efficient climb out.**



1. The goal for this element is a noise reduction of 6 EPNdB thru efficient high lift devices and noise abatement procedures.
2. The goals assume that thrust cutback will be possible while maintaining the same climb angles as today's technology designs. The means that climb lift-to-drag ratios must improve by at least 20%.

# HSCT COMMUNITY NOISE TECHNOLOGY Challenge



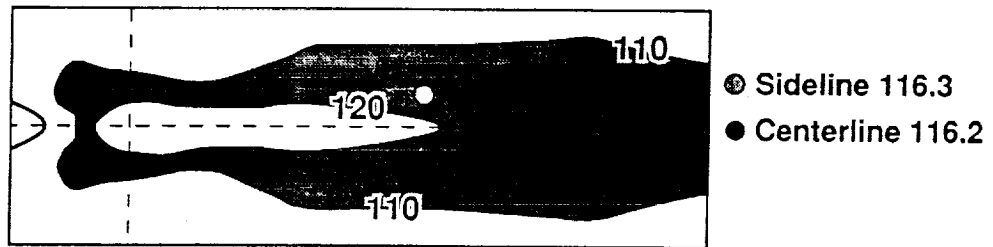
(4) Engines  
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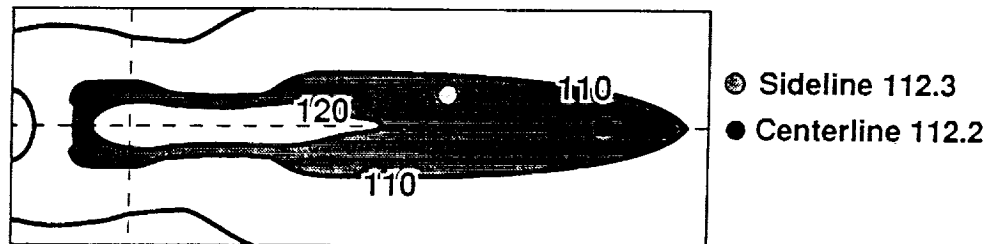
**1. The 6 EPNdB savings means that the engine noise suppression requirements can be relaxed - or the engine need not be oversized - or that the margin for design error can be greater and still meet the Stage III limits.**

## ANOPP SYSTEM NOISE PREDICTION FOR HSCT Effective Noise Level Contours (EPNdB)

100% THRUST, STANDARD LIFT CONFIGURATION



80% THRUST, 30% LIFT INCREASE



⊙, ● NOISE CERTIFICATION POINTS

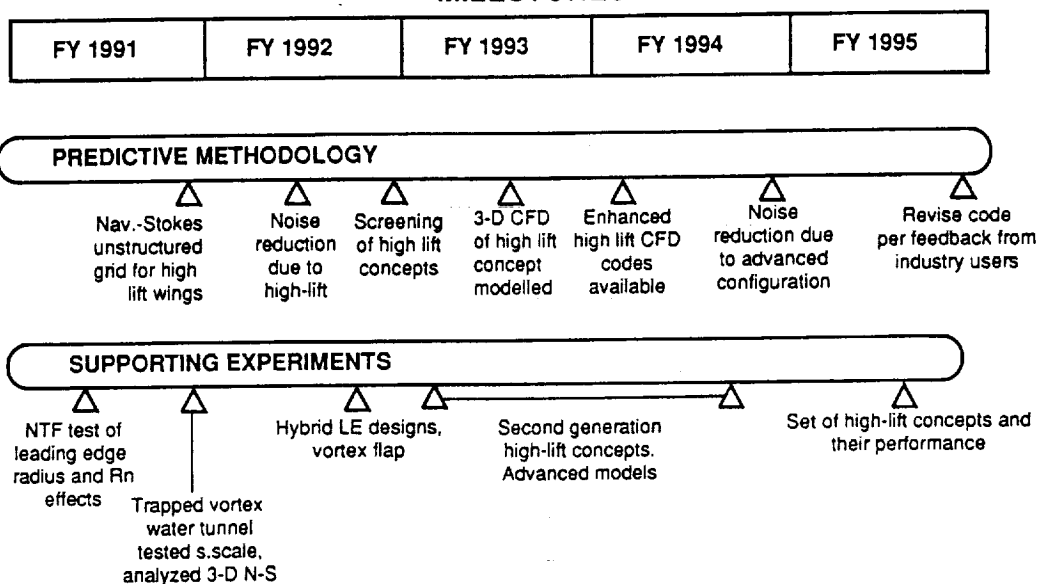
1. The best way to depict the noise savings is in terms of footprint or ground contour.
2. At 80% thrust, the obvious effect of improved technology is a better L/D. (30% increases lift refers to a higher lift coefficient, enabling lower speeds and hence less drag.)
3. Some leeway may be required in the way the FAA assesses noise impact since the two certification points do not adequately measure total noise impact.



## **HIGH LIFT SYSTEMS**

AERODYNAMICS DIVISION

### **MILESTONES**

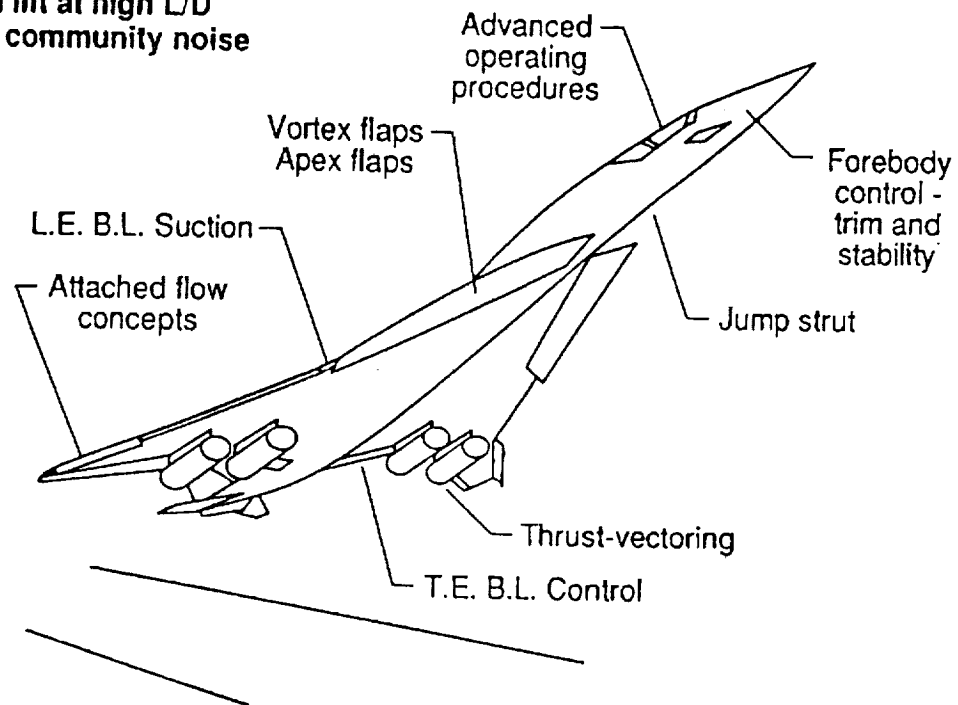


1. The program plan for high lift is depicted here for the record.
2. The efforts result in wind tunnel tests of various concepts and code validation to match the results. These results will be picked up in Phase II for integration and flight test validation.

## ***HSR HIGH-LIFT ADVANCED CONCEPTS***

### **GOALS**

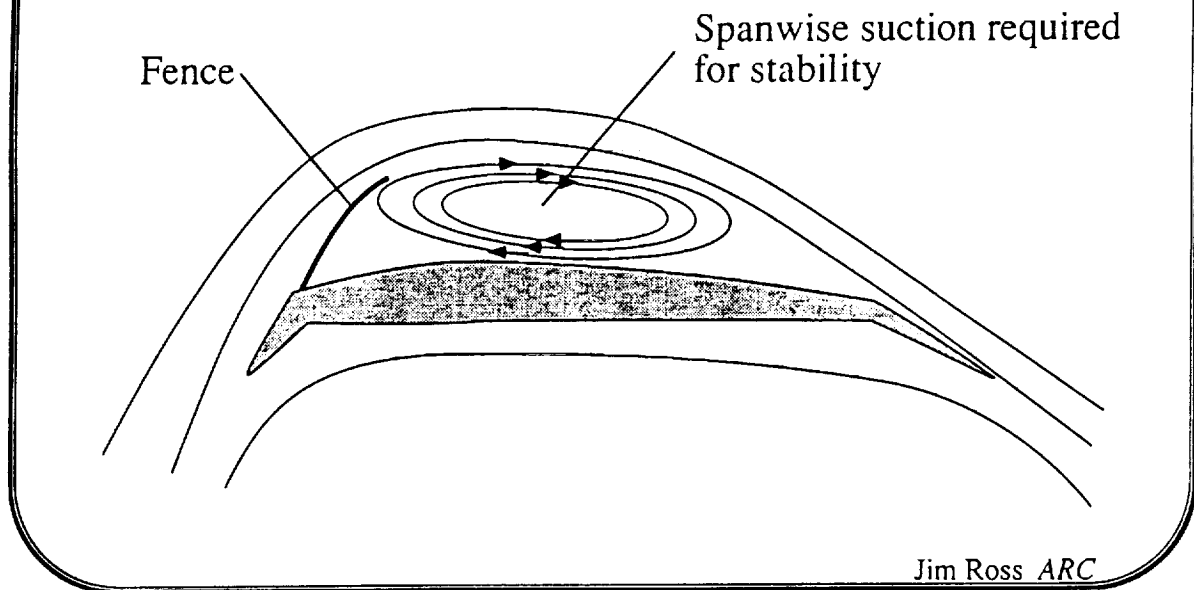
- Early rotation
- High lift at high L/D
- Low community noise



**1. This sketch depicts many of the high lift technologies that have been planned.**

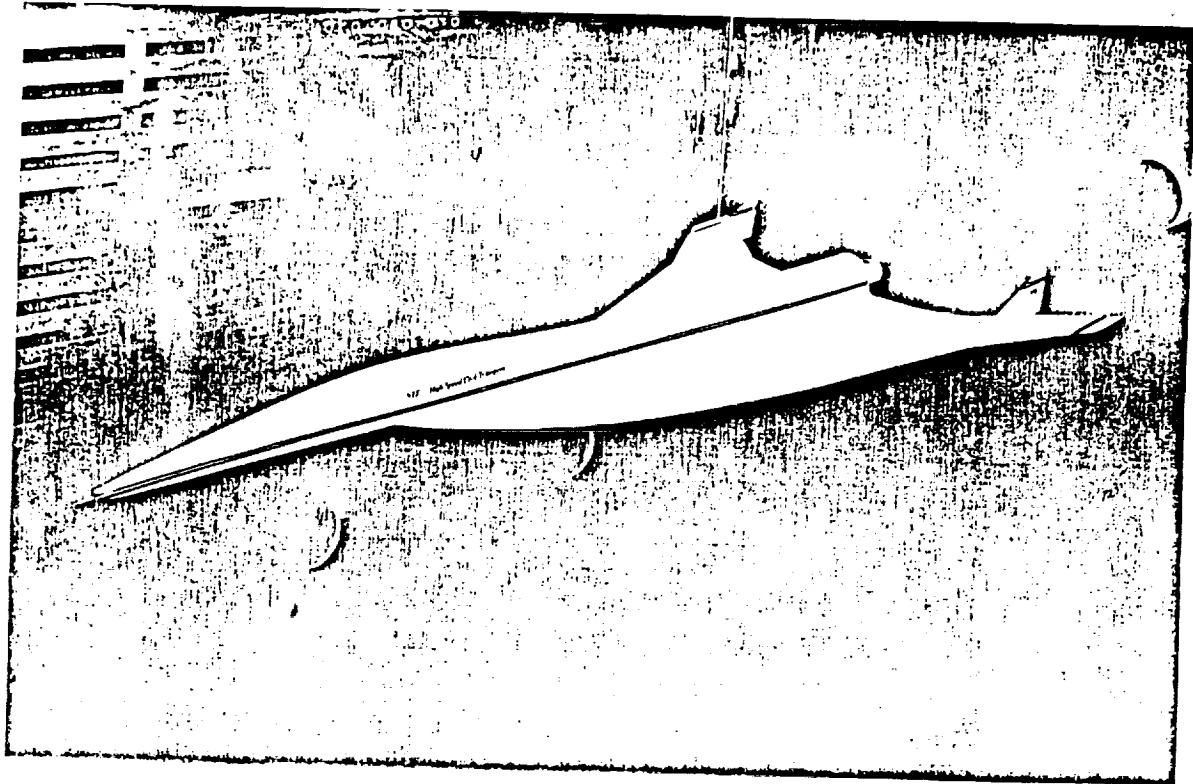
# HSR High-Lift Systems Concept Development

## Trapped vortex concept

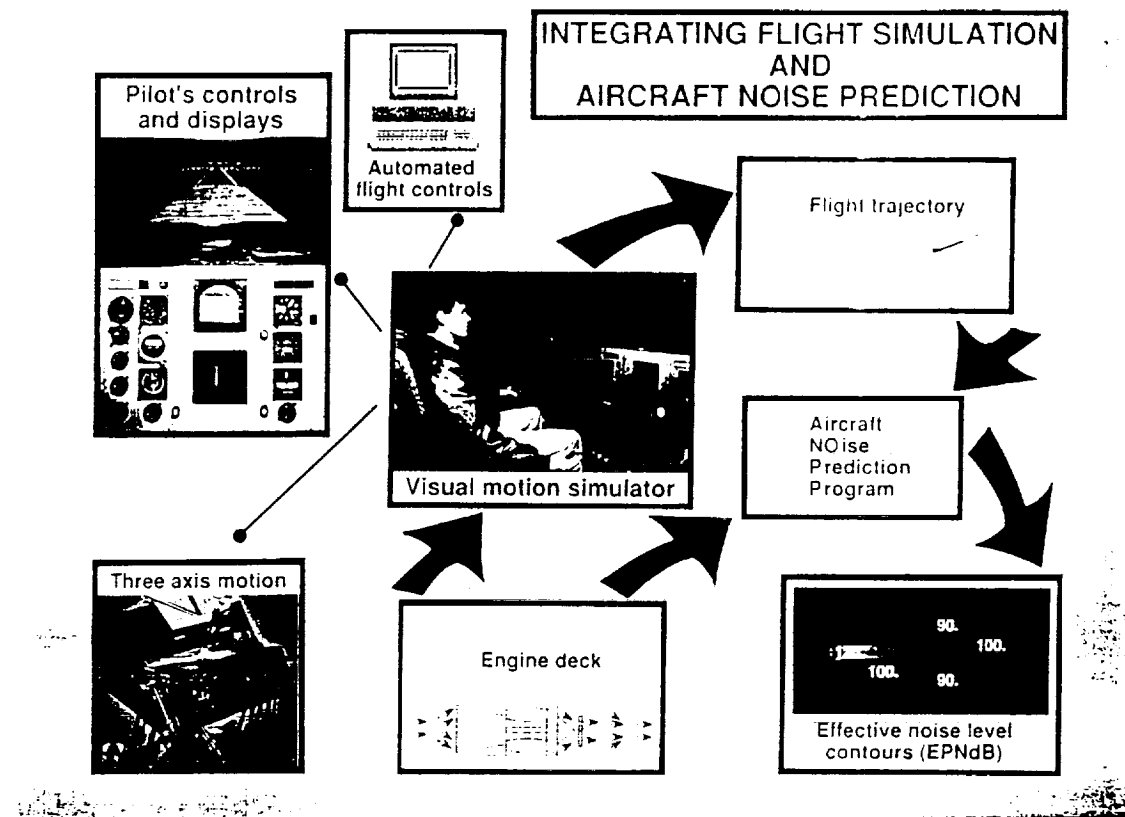


1. One of the early results from Ames is the trapped vortex concept.
2. The drag was unacceptably high unless a rearward fence was incorporated.
3. Further testing is planned to find ways to eliminate the requirement for spanwise suction on a swept wing.

## HIGH-LIFT STUDY IN THE NATIONAL TRANSONIC FACILITY REYNOLDS NUMBER AND LEADING EDGE RADIUS EFFECTS



1. Langley has conducted exploratory testing in its 12-ft, 14x22-ft and NTF wind tunnels.
2. The NTF provides a high Reynolds number similitude for understanding the effects of scaling of model HSR wings.



1. The final test of any of these high lift devices is integration into an aircraft.
2. Depicted here is the logic of testing that integrated aircraft in a piloted simulation that yields flight trajectories and engine settings.
3. These data are then coupled into ANOPP to predict noise contours.
4. First trials of the above procedure have been completed. It will be an extremely useful means of evaluating noise impact quickly.

## ***HIGH LIFT SYSTEMS***

---

### **STATUS**

- ANOPP applied to high lift and operational procedures
- Concept screening initiated
- Piloted simulation of operational procedures

### **CONCERNS**

- Compatibility/integration of high-lift systems with supersonic laminar flow control and low-boom planforms

**1. There has not been much early success in this element with new high lift devices. The problem is the attendant drag that seems to accompany the higher lift results. In some cases this has led to solutions for a second round of testing.**

**2. The FAA will have to be an early player in assessing the safety of the low noise, multi-mode takeoff profiles. Automation of takeoff and climb will have to be examined later in the HSR program.**

**3. It is clear that some high lift devices will not be appropriate for low boom or laminar flow control. There should be a first-pass criteria that recognizes these integration issues.**

## ***COOPERATIVE EFFORTS***

---

- RN and leading-edge radius effects (Boeing)
- Leading-edge BLC/suction system (Boeing)
  - Avoid l.e. separation
  - Simulate high RN conditions
- Wing fence/flap concepts (Boeing)
- Forebody flow control (Boeing)
- Wing apex blowing concepts (Douglas)
- High-lift design methods (Douglas)
- Longitudinal and lateral trim concepts (Boeing & Douglas)
- Piloted simulation of advanced aero and operating procedures for noise reduction (Boeing & Douglas)

**1. The high lift element has the lowest funding of any element. It owes its success and progress in part to numerous cooperative activities with industry.**

**2. The above list contains some of the past and planned cooperative efforts with industry. Obviously more will be planned as clear success can be shown.**

## SONIC BOOM RESEARCH

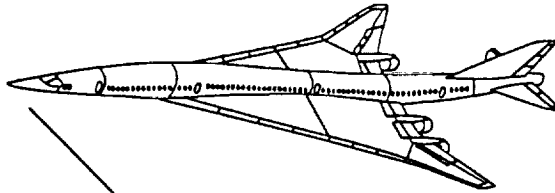
Civil supersonic flight over land is currently not allowed in the U.S. (Ref: FAR 91) and many other places. European HSCT studies seem to assume no solution is possible for the boom problem, and NASA sponsored studies by Boeing and Douglas indicate economic viability for an aircraft that would be primarily limited to over water supersonic operation, and limited subsonic operation over land. However, supersonic overland flight would be a significant economic benefit, and the HSRP is pursuing attractive low boom concepts, including low supersonic speeds over populated areas. By late 1992, enough wind tunnel and subjective response data should be available to allow a system study based decision on low boom feasibility.

### SONIC BOOM RESEARCH

- FAR 91 RESTRICTS NORMAL OPERATION OF CIVIL AIRCRAFT IN THE U.S. TO SUBSONIC SPEEDS
- SIMILAR RULES RESTRICT SUPERSONIC AIRCRAFT IN OTHER COUNTRIES
- HSCT STUDIES INDICATE VIABILITY FOR LIMITED SUBSONIC OPERATION OVER LAND
- SUPERSONIC FLIGHT OVER LAND WOULD BE A SIGNIFICANT ECONOMIC BENEFIT
- HSRP GOALS
  - ESTABLISH ACCEPTABILITY CRITERIA
  - PREDICTIVE METHODOLOGY FOR LOW BOOM CONCEPTS
  - VERIFY PREDICTION CAPABILITY
  - SYSTEM ANALYSIS OF TECHNICAL & ECONOMIC PERFORMANCE
- POSSIBLE PROGRAM REDIRECTION IN '92 COORDINATED WITH LOW BOOM RESEARCH PROGRESS



# HSR SONIC BOOM TECHNOLOGY



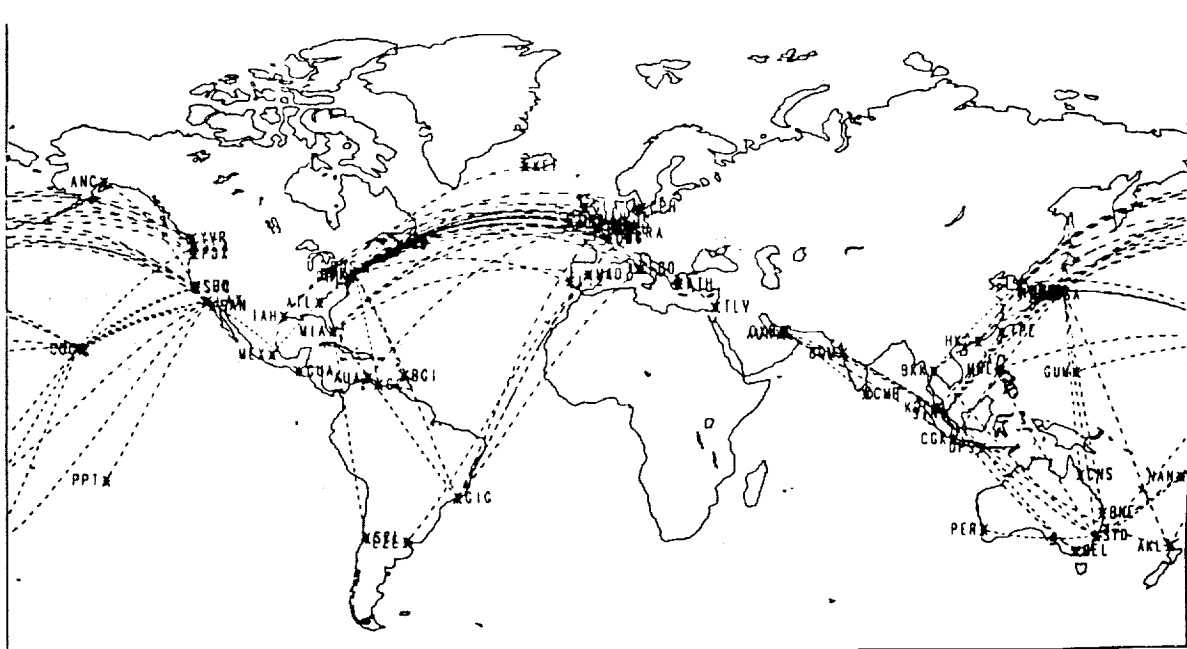
## STATUS REPORT

### 1ST ANNUAL HIGH-SPEED WORKSHOP

MAY 14, 1991

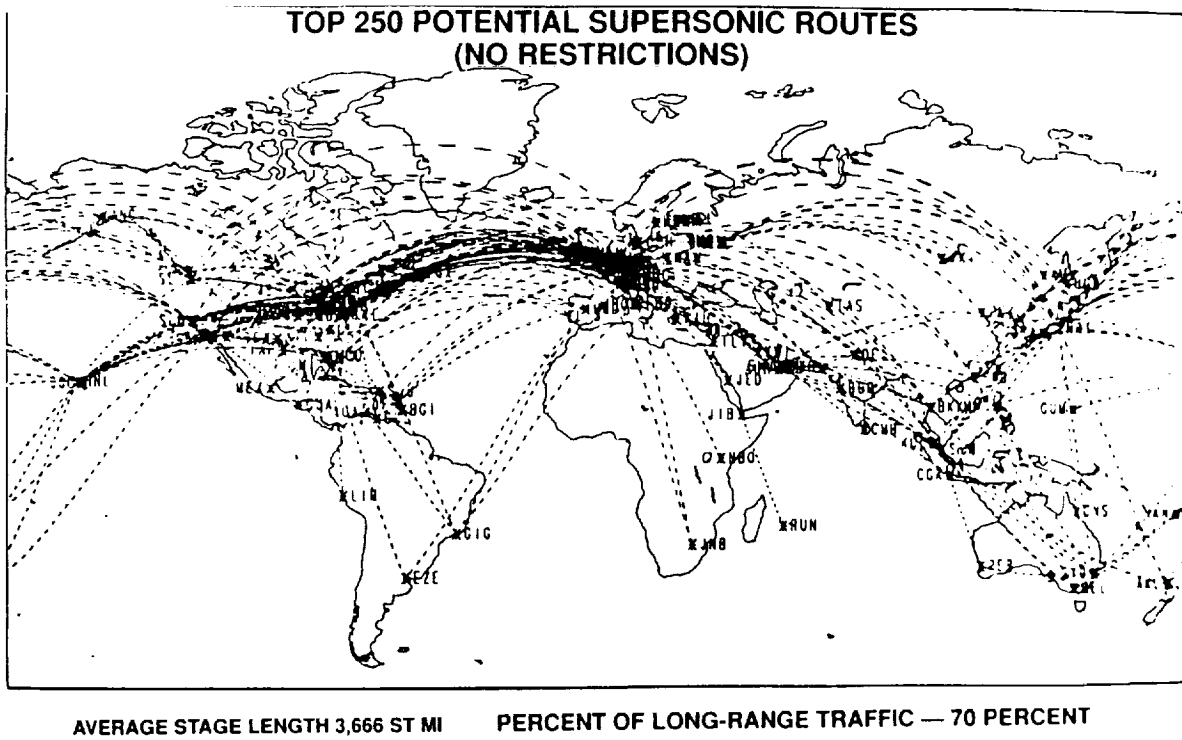
GEORGE UNGER  
MANAGER, VEHICLE AERODYNAMICS  
AERODYNAMICS DIVISION  
OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY

1. Sonic boom, high lift and supersonic laminar flow control technology areas are covered by the Aerodynamics Division.
2. Kevin Shepherd of Langley helped prepare this charts during a three month stay at Headquarters.
3. George Unger will be officially handing over oversight of these areas to Benjarmin Neumann after this workshop. Benjy comes to Headquarters from NAVAIR.

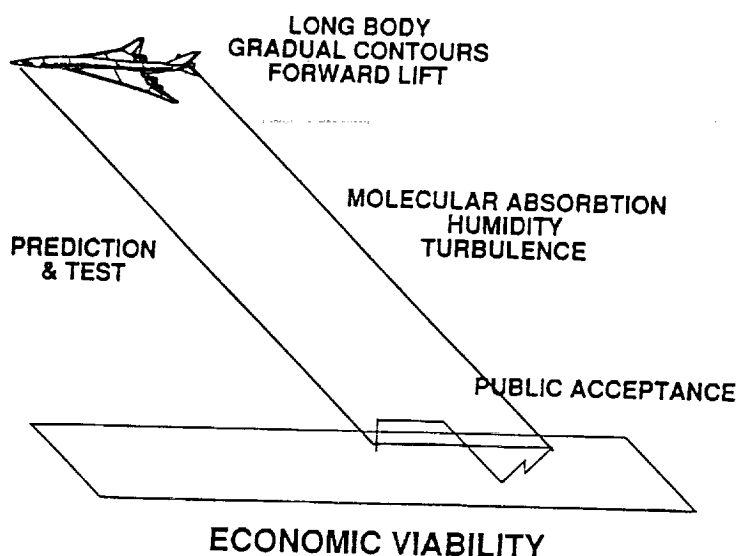


AVERAGE STAGE LENGTH 3,900 ST MI      PERCENT OF LONG-RANGE TRAFFIC — 28 PERCENT

1. The importance of reducing sonic boom cannot be overstated.
2. Douglas study: overwater routes account for only 28% of long range traffic projected in 2010.
3. (next page) If there were no boom restrictions, a proposed HSCT could capture 70% of the long range traffic.



## SONIC BOOM ENVIRONMENTAL QUESTIONS



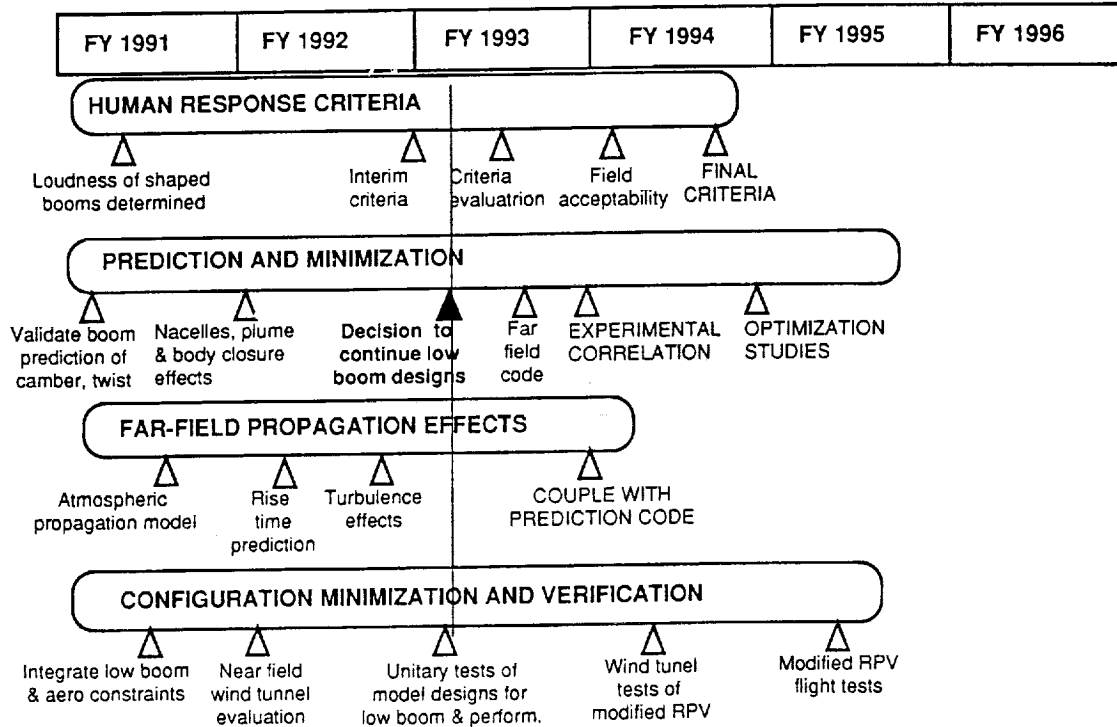
1. The technical questions fall into the 4 areas indicated:

- design tradeoffs - affects economic viability
- propagation through the atmosphere
- prediction of boom signature from aircraft geometry and small-scale wind tunnel testing
- criteria for public acceptance of the low boom signature

2. Not listed at this stage are the effects of acceleration, deceleration and maneuver on the boom signature. These areas will have to be evaluated in any case for near land operation since they can focus the boom into a more intense sound.

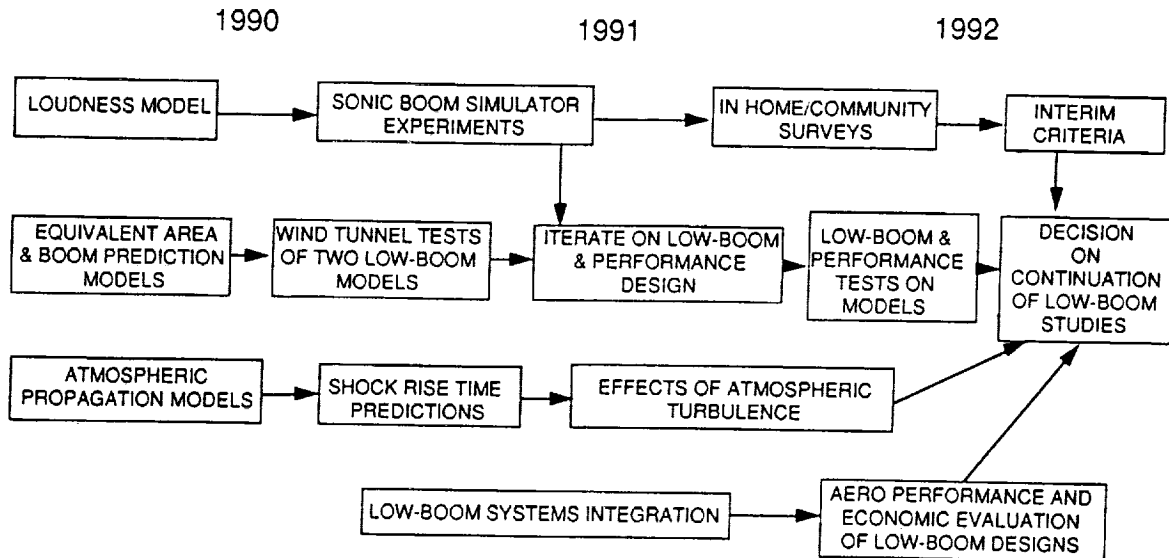
# SONIC BOOM REDUCTION AERODYNAMICS DIVISION

## MILESTONES



1. Chart represents the milestones that we are tracking. It is included here for reference.
2. Note that there is a decision in December 1992 to continue exploring low boom designs. The low boom work is viewed with some skepticism as to its practical application. Therefore an early assessment is warranted.

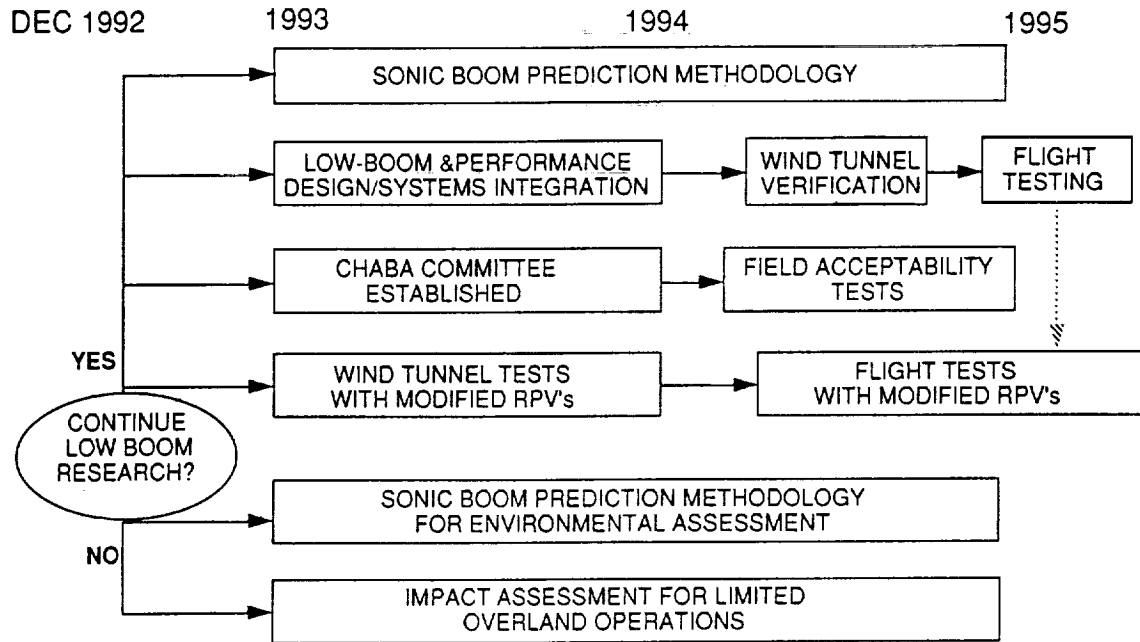
BEFORE DECEMBER 1992



1. The necessary ingredients that must be in hand to make that decision are depicted here.
2. An iterated design is the first step followed by an economic evaluation of its merits. The tradeoff may be added weight per passenger vs. increased market size.
3. Finally an assessment of how close the propagated boom signature comes - on a statistical basis - to the proposed acceptance criteria in the community.

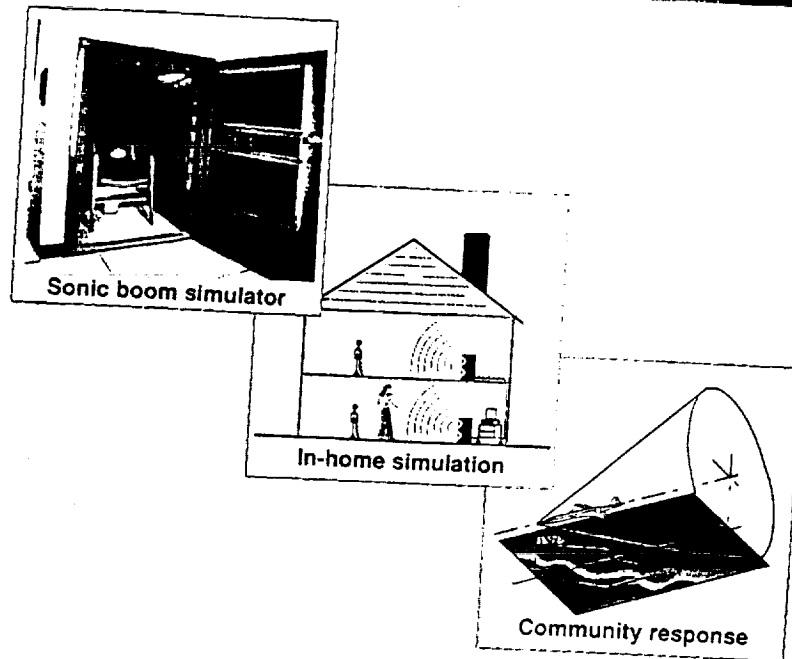
## SONIC BOOM RESEARCH PLAN

BEYOND DECEMBER 1992



1. Some recent results are presented here.
2. A "boom box" has been constructed to expose subjects to different boom signatures.
3. Work is also underway to test boom exposures inside buildings such as residences.
3. Finally, some effort is being undertaken in cooperation with the USAF to survey communities that were repeatedly boomed by SR-71 flights in the past.

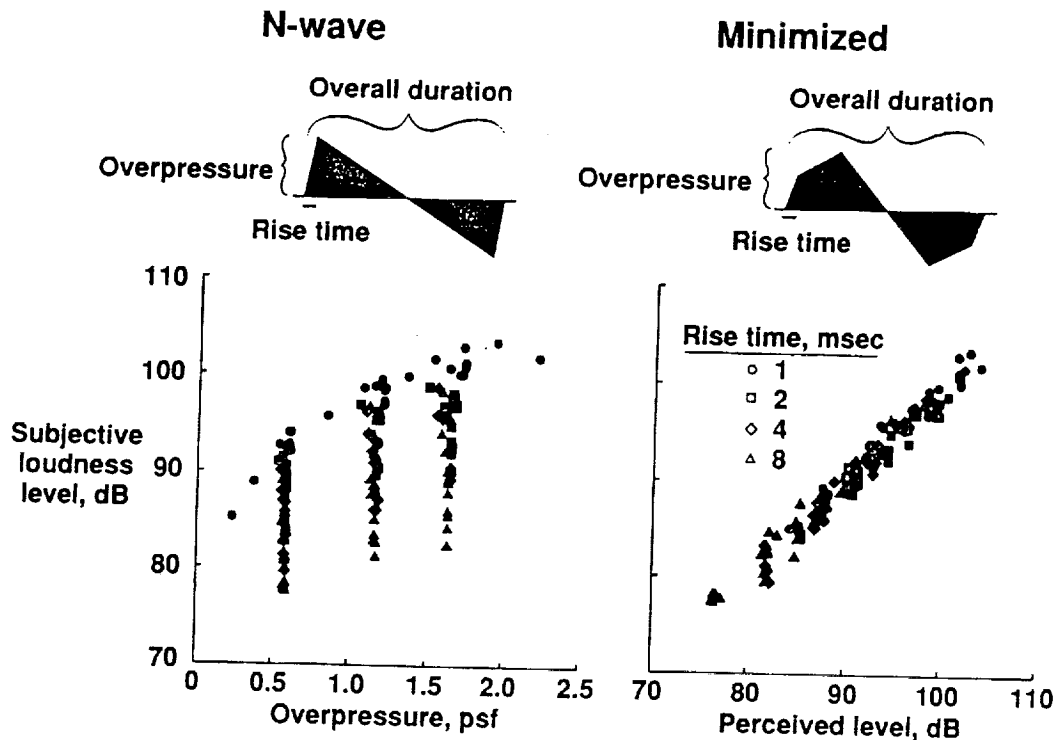
## SONIC BOOM ACCEPTABILITY CRITERIA



1. If the decision is favorable, then flight testing is in order with modified RPV's. This approach represents the cheapest way to test signature propagation in the real world.
2. Further refinement of the methodology and designs will be necessary.
3. Finally, a committee of experts must be established to supervise and recommend boom acceptability trials.
4. If the decision is to curtail low boom research, then some further research is warranted to understand near land operations, over island booms, and maneuvers, accelerations and decelerations.

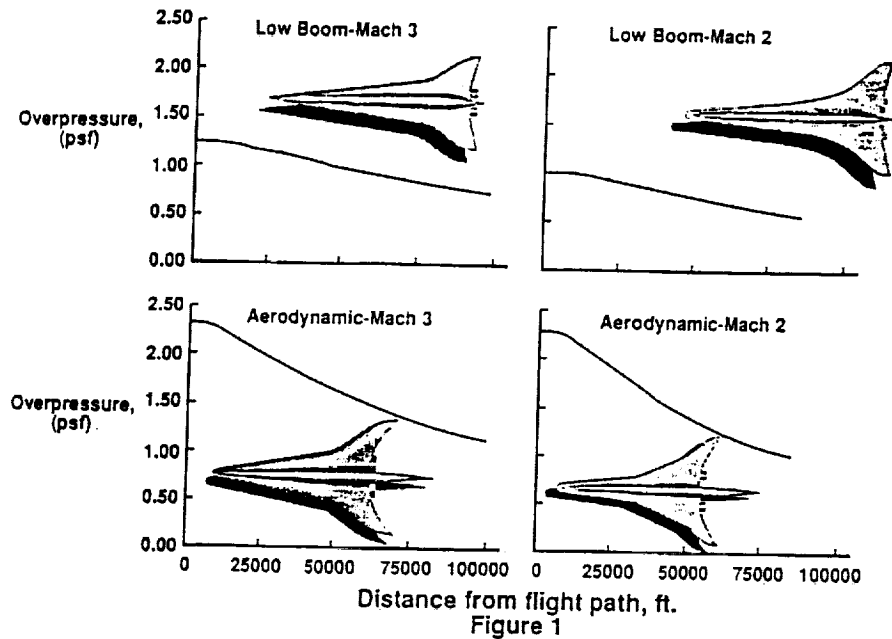


# PREDICTION OF SUBJECTIVE RESPONSE TO SONIC BOOMS

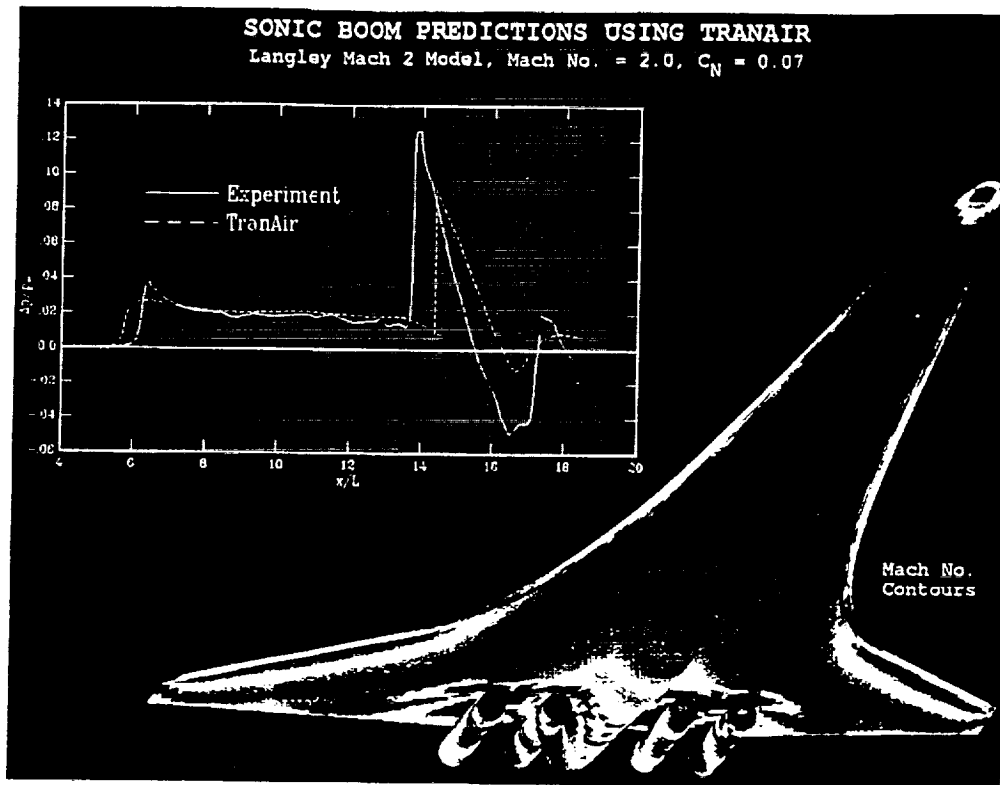


1. The typical "N" wave from a sonic boom is a pressure signature that is characterized by a peak overpressure and a rise time for the initial pressure wave.
2. Making the rise times longer results in a boom sounding less like a crackle or thump and more like a rumble or whump. Peak overpressure affects the intensity and the atmospheric dissipation characteristics. The left chart shows that the shortest rise times (circles) exhibit the most subjective loudness.
3. "Loudness" appears to be the more consistent measure of annoyance, as shown by the right hand chart.
4. Target overpressures are at or below 1 pound per square foot (psf).

## SONIC BOOM BOW SHOCK LEVELS AS A FUNCTION OF DISTANCE FROM FLIGHT PATH



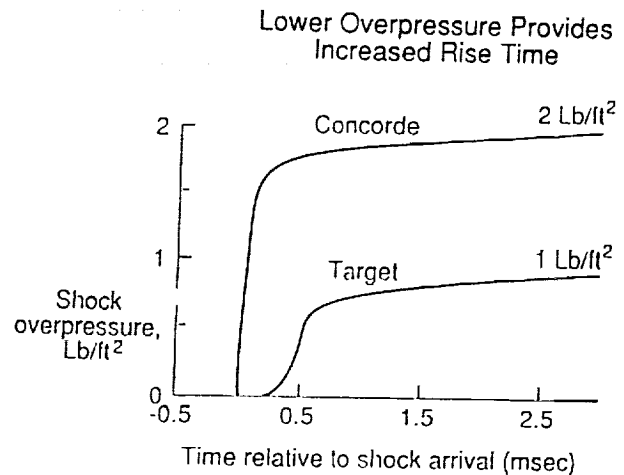
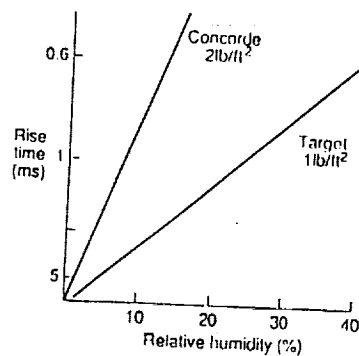
1. Another concern of the low boom design was off-axis signature. If the configuration yielded a low overpressure directly under the flight path, would that remain true to the left and right of the center line signature laid on the ground?
2. The top figures show that the low boom overpressure does not rise with increasing distance along the sideline. Indeed, even at 100,000 feet (19 miles) perpendicular to the flight path axis, the low boom design has a lower overpressure than a design that would not have considered sonic boom as a design parameter.



1. Another concern is the reliable prediction of the boom pressure waves from analytical descriptions of the aircraft geometry.
2. Tests were run in the Ames and Langley Unitary tunnels to get pressure signatures close to and some distance (3 body lengths) away from the center line.
3. Except for support strut interference at the back of the model, TRANAIR does a reasonable job of predicting initial overpressures.
4. The peak pressure spike at  $x/l = 14$  is due to the blocked engine inlets which will not be present in future tests.
5. The comparison of tests in the Ames And Langley tunnels shows that the smaller test section of the Langley facility is quite adequate for boom testing on these models (which are roughly 12" in length).

## ATMOSPHERIC ABSORPTION EFFECTS ON SONIC BOOM WAVE FORMS

Lower Overpressure Less Sensitive  
to Humidity Effects



1. Propagation results to date have shown favorable effects when compared to the higher overpressures of the Concorde SST.
2. Humidity, which reduces rise time by allowing faster transport of the acoustic wave, has less dramatically less impact for a 1 psf signature.
3. Similarly, molecular absorption increases rise time for a more benign signature.

## ***SONIC BOOM REDUCTION***

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### **STATUS**

- Methods for low boom design validated by wind tunnel testing
- Atmospheric absorption compounds benefit of boom minimization
- Human response studies confirm substantial benefit of boom minimization

### **CONCERNS**

- Configuration compatibility with high-lift goals

- 1. Progress in this area has been rapid and continues to show promise.**
- 2. Some form of boom minimization may be attractive in a baseline HSCT if only to recognize the problems with near land booms.**
- 3. The decision to continue working towards a low boom design requires an understanding of the integration issues. The study tasks identified for this concern may not be sufficient to answer all the issues.**

## HSCT WEIGHT REDUCTION RESEARCH

In general, HSCT weight reduction would benefit environmental compatibility as well as economics, with a larger direct payoff for emissions and sonic boom. However, economic benefits of weight reduction are critical.

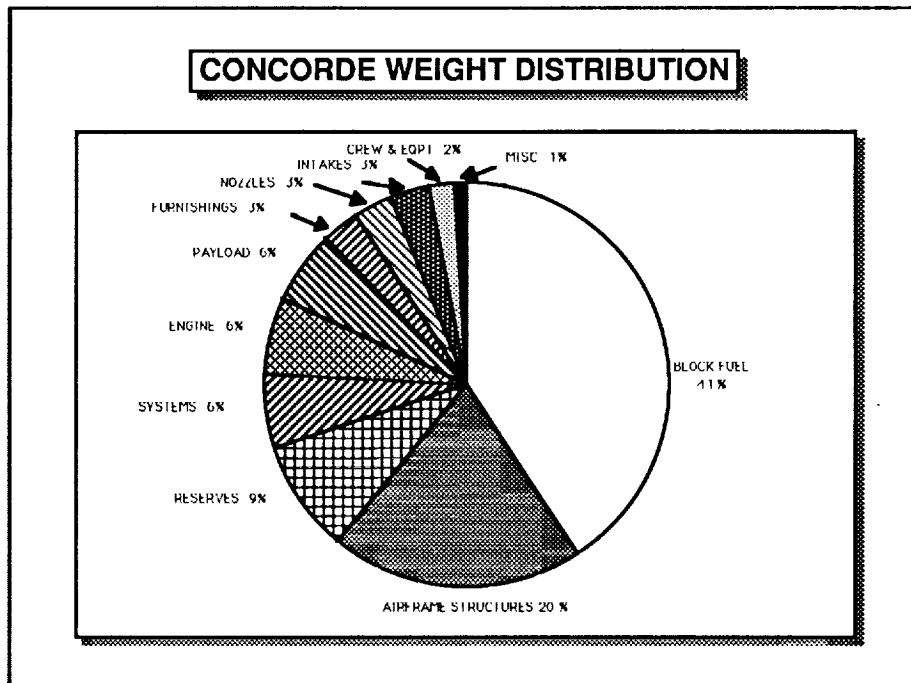
### HSCT WEIGHT REDUCTION RESEARCH

- **ENVIRONMENTAL IMPACT**
  - EMISSIONS & SONIC BOOM APPROXIMATELY PROPORTIONAL TO AIRCRAFT WEIGHT
  - NOISE LOGARITHMICALLY PROPORTIONAL TO AIRCRAFT WEIGHT
- **ECONOMIC IMPACT**
  - FUEL IS LARGEST WEIGHT COMPONENT
  - SMALL PAYLOAD FRACTION PROVIDES HIGH LEVERAGE FOR DESIGN TRADES
- **HSRP ELEMENTS**
  - SUPERSONIC LAMINAR FLOW CONTROL RESEARCH
  - MATERIALS & STRUCTURES SYSTEMS TECHNOLOGY (PHASE II)

## CONCORDE WEIGHT DISTRIBUTION

These Concorde data typify qualitative aspects of HSCT weight distribution. Advanced design should allow a somewhat more favorable distribution for economics (e.g., less structure, more payload). However, fuel will continue to be a very large fraction at about 50 percent, which shows the importance of all forms of performance efficiency improvements, including aerodynamics, propulsion, and structure. The small payload fraction shows the high leverage benefits for small reductions in other weight contributors, and emphasizes the importance of HSCT weight reduction efforts.

The HSRP includes supersonic laminar flow control research as a promising means for weight reduction. A parallel Materials & Structures Systems Technology Program with more broad aircraft goals has also begun to study HSCT applications as a precursor for Phase II of the HSRP.



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# **HSR SUPERSONIC LAMINAR FLOW CONTROL TECHNOLOGY**

## **STATUS REPORT**

### **1ST ANNUAL HIGH-SPEED WORKSHOP**

**MAY 14, 1991**

**GEORGE UNGER  
MANAGER, VEHICLE AERODYNAMICS  
AERODYNAMICS DIVISION  
OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY**

- 1. This element represents the largest aerodynamic element and, perhaps the one with the most controversy.**
- 2. The success of the subsonic laminar flow control flight testing and preliminary testing at supersonic speeds has led to the belief that maintaining significant laminar flow is possible for the HSCT.**
- 3. The major questions require demonstration as I shall outline.**

## ***SUPERSONIC LAMINAR FLOW CONTROL***

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### **BENEFITS**

- REDUCTIONS IN

SONIC BOOM LEVELS

COMMUNITY NOISE

ENGINE EMISSIONS

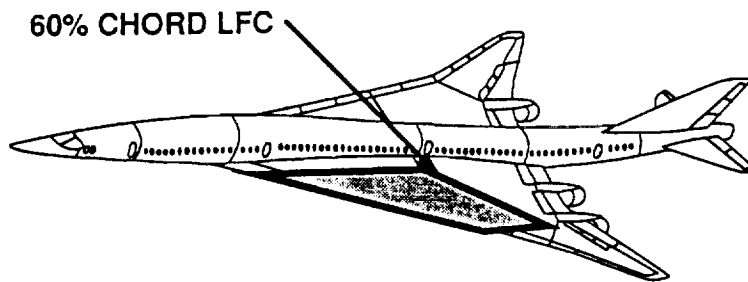
• LIFT / DRAG INCREASE	12 - 17%	or RANGE +10 - 12%
• FUEL BURN DECREASE	14 - 18%	
• GROSS WEIGHT DECREASE	7 - 10%	

(NASA CR-181817)

- 1. The above summarizes the benefits predicted on the basis of a re-designed aircraft that incorporated SSLFC from the start.**
- 2. The risk of using the SSLFC as a baseline design is the converse of the above: failure will result in the opposite of the benefits. That is to say, if the production airplane was designed for SSLFC with the expectation of the benefits of reduced fuel usage and it did not occur, there would be a shortfall in range of 10-12%.**

## SSLFC QUESTIONS

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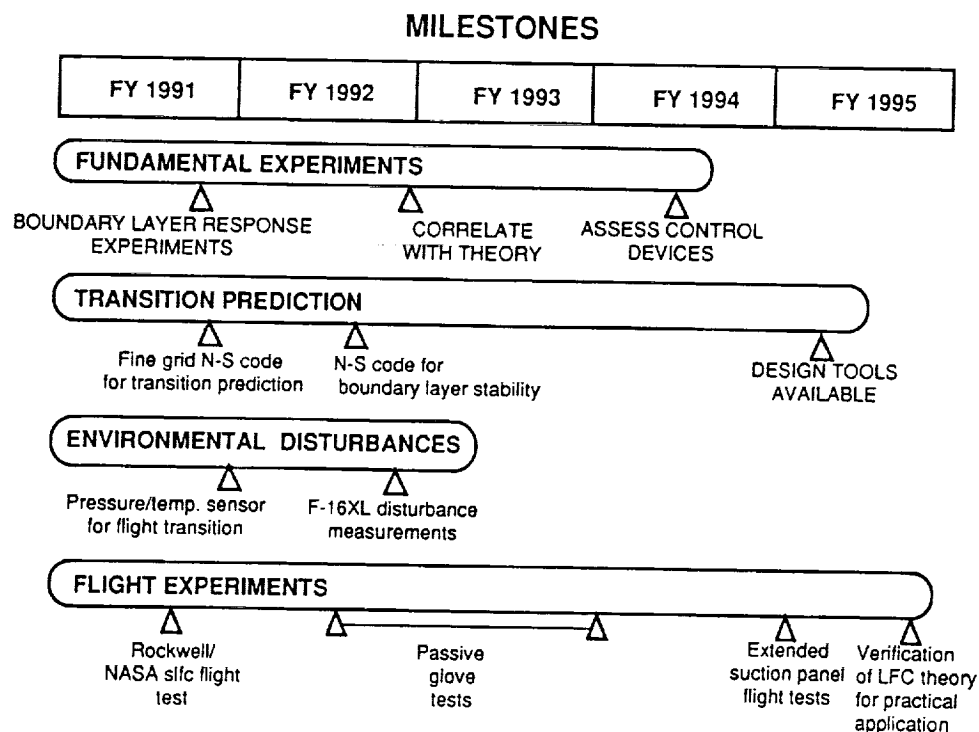
CROSS FLOW /LEADING EDGE CONTAMINATION  
SUCTION POWER REQUIREMENTS  
OFF DESIGN PERFORMANCE

SYSTEM INSTALLATION  
REQUIREMENTS

DEMONSTRATE  
@ LARGE SCALE R.N.

1. The leading questions I referred to earlier are depicted here.
2. These questions have focused this element on a large scale demonstration of SSLFC on an F-16XL aircraft. Smaller scale experiments simply do not represent the actual hardware and results that are expected on a production HSCT.

# **SUPERSONIC LAMINAR FLOW CONTROL** AERODYNAMICS DIVISION

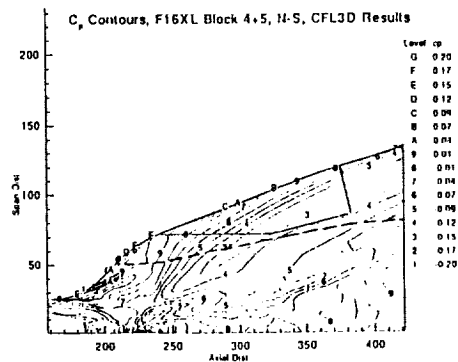


1. The program plan is included here for the record.
2. The goal is the earliest possible flight test of a full system glove on the F-16XL in order to influence the baseline HSCT design.

## SUPERSONIC LAMINAR FLOW CONTROL

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### COMPUTATIONAL TOOLS IN PLACE

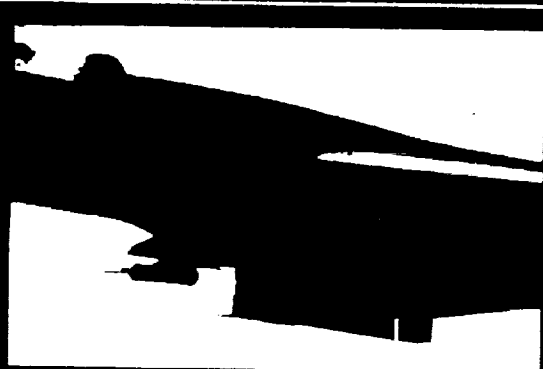


- MEAN FLOW ANALYSES FROM 2 NAVIER-STOKES CODES
- LINEAR BOUNDARY STABILITY CODE, MODIFIED FOR 3-D COMPRESSIBLE FLOW
- COUPLING OF N-S RESULTS TO STABILITY CODE YIELDS ACCURATE PROFILES FOR TURBULENT TRANSITION WITH AND WITHOUT SUCTION
- CONTAMINATION ALONG LEADING EDGE AND REAR OF CANOPY UNDERSTOOD

~~C-4~~

## Advanced Sensors For Transition Research

Ames Fluid Mechanics Laboratory



sensor will be mounted here

### F104 Flight Test Fixture

- Temperature/Pressure Sensitive Paint Feasibility Study
- Flight-qualification
- Use of sunlight as excitation source...

### F16XL Program

- Temperature/Pressure Sensitive Paint
- Liquid Crystal Shear Sensors

video camera

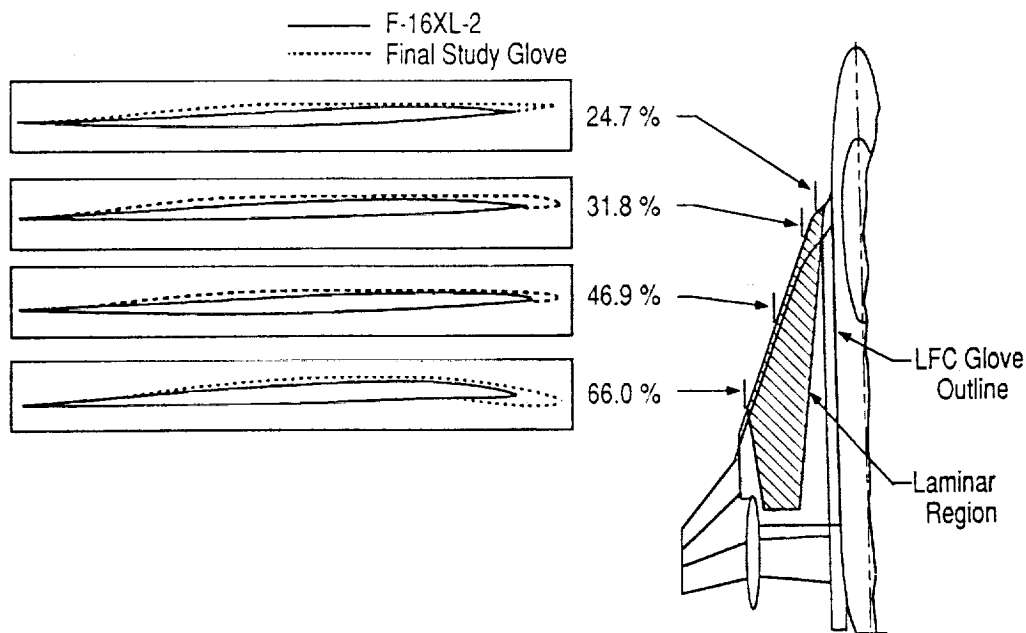
active glove



1. A sub-element of this activity is the development of sensors that accurately measure the transition point between laminar flow and turbulence onset.

2, The slide (reproduced here in poor quality) shows a combination of sensors that will be incorporated on the SSLFC test aircraft.

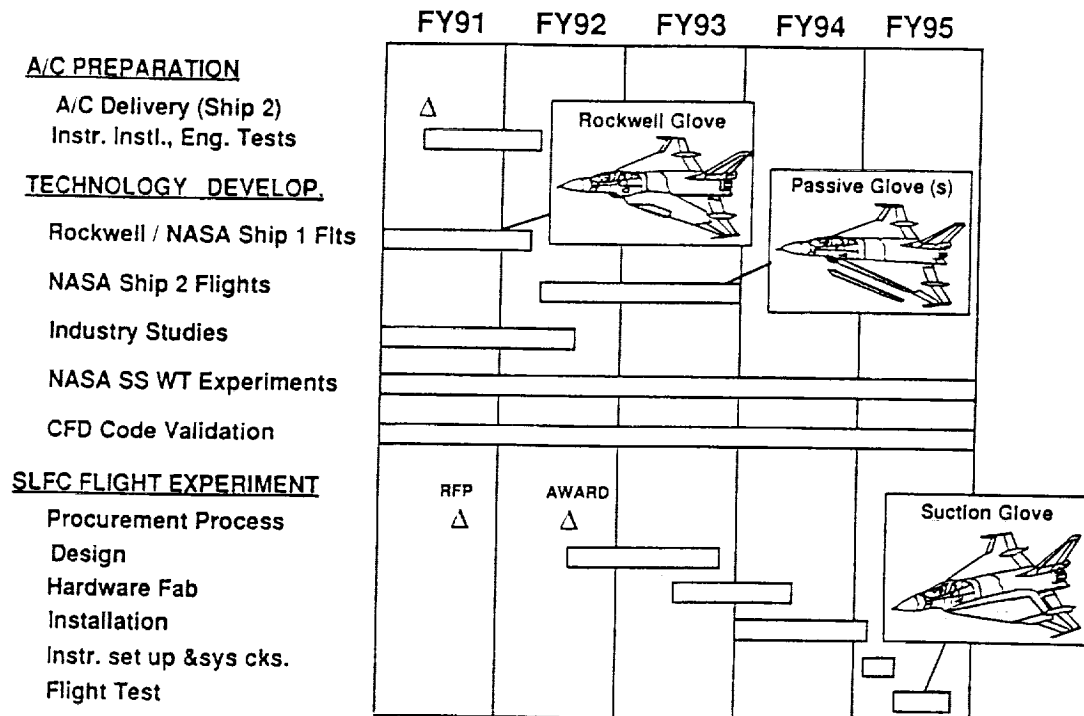
## DAC F-16XL-2 SLFC DESIGN FEASIBILITY STUDY



1. An early result of the design activity is shown above. Douglas has shown analytically that a proper glove can be wrapped around the wing without penetrating the existing contours of the F-16XL.

2. The design will have the flexibility of testing different suction regions at varying suction rates to examine the system design requirements.

## F-16XL SUPERSONIC LAMINAR FLOW CONTROL EXPERIMENT



1. The project plan for the flight testing is shown here.
2. Key to the success of the coordination of the activity is the use of both F-16XL aircraft to provide a broader basis to the final design that is demonstrated.



## ***SUPERSONIC LAMINAR FLOW CONTROL***

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### **STATUS**

- SLFC achieved by Rockwell/NASA flight test
- F-16XL glove design for 60% chord SLFC is feasible (Douglas)
- Codes in place for transition in supersonic swept wings

### **CONCERNS**

- Compatibility/integration of SLFC with leading edge high-lift devices

- 1. The Rockwell tests are encouraging and the data is being used to understand the limitations of the F-16XL.**
- 2. Without some understanding of the integration issues, it will be difficult to assess the full merits of some high lift devices. In addition, the availability of suction may offer high lift ideas that merit evaluation.**
- 3. Integration with low sonic boom ideas is also a concern. Except for possible leading edge compromises in the airfoils, this issue is unclear.**

## MAJOR ACCOMPLISHMENTS TO DATE

Significant accomplishments have been achieved in the first 1 1/2 years of the HSRP. In particular, research results promise achievement of emissions and noise goals, and the feasibility of low boom concepts. However, much additional effort will be necessary before the overall program is successfully concluded.

### MAJOR ACCOMPLISHMENTS TO DATE

- **ATMOSPHERIC RESEARCH**
  - 2-D MODEL ASSESSMENT
  - CHEMISTRY LAB EXPERIMENTS
  - FIELD CAMPAIGN PLANNING
- **EMISSIONS REDUCTION**
  - ADDITIVES EVALUATION
  - CFD APPLICATION
  - FLAMETUBE DEMONSTRATION OF LPP CONCEPT
- **SOURCE NOISE REDUCTION**
  - CFD APPLICATION
  - MIXER/EJECTOR NOZZLE AEROACOUSTIC PERFORMANCE
- **COMMUNITY NOISE**
  - ANOPP APPLICATION
  - HIGH-LIFT CONCEPT SCREENING
  - PILOTED SIMULATION OF OPERATIONAL PROCEDURES
- **SONIC BOOM**
  - CFD APPLICATION
  - PHASE I LOW BOOM CONCEPT W.T. TESTS
  - SUBJECTIVE RESPONSE EVALUATION
- **SUPERSONIC LAMINAR FLOW CONTROL**
  - CFD APPLICATION
  - FLOW MEASUREMENT PROCEDURES
  - F-16XL AIRCRAFT ACQUISITION

## PROGRAM SUMMARY

In the near term, progress towards achievement of program goals will demonstrate readiness for initiation of a more vehicle focussed technology program that, in turn, would complete the foundation for an industry aircraft development program. As indicated earlier, it is currently planned to begin Phase II of the HSRP in FY 93.

### HIGH-SPEED RESEARCH PROGRAM

#### PROGRAM SUMMARY

A SUCCESSFUL CONCLUSION OF THE INTERRELATED RESEARCH EFFORTS WILL DEMONSTRATE:

##### EMISSIONS

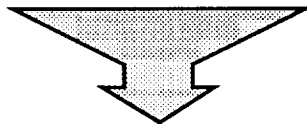
- Feasibility of 90% NO<sub>x</sub> Reduction to EI = 3 to 8
- Validity of HSCT Ozone Effect Predictions
- Acceptability of Emission Levels

##### AIRPORT COMMUNITY NOISE

- Feasibility of Economically Viable Compliance with FAR 36 - Stage 3

##### SONIC BOOM

- Feasibility of Acceptable Supersonic Overflight or Economic Viability Assuming Subsonic Overflight Restriction



READINESS FOR INITIATION OF HIGH-LEVERAGE TECHNOLOGY DEVELOPMENT PROGRAM

## **WORKSHOP TECHNOLOGY SESSIONS**

The purpose of the following workshop sessions is to describe important technological accomplishments in the HSRP, to review the content of each program element, and to discuss planned activities and key milestones. In general, each session should begin with an overview, and be followed by presentations summarizing the key results to date. Sufficient discussion time should be allowed for active involvement of technical specialists within each program element. Following completion of each technology session, chairmen and rapporteurs are to prepare reports for HSRP management, summarizing session presentations and recommendations regarding midcourse corrections in objectives and plans. Emphasis should be on program level milestones.

### **FIRST ANNUAL HIGH-SPEED RESEARCH WORKSHOP**

#### **WORKSHOP TECHNOLOGY SESSIONS**

**WEDNESDAY, MAY 15, 8:30 A.M. THRU THURSDAY, MAY 16, NOON**

##### **OBJECTIVES**

- **OVERVIEW OF STATUS AND PROGRESS**
- **PAPERS SUMMARIZING KEY RESULTS, PLANS, ETC**
- **OPEN DISCUSSION**
  - **ASSESSMENT OF PROGRESS VS PLANS**
  - **CONSIDERATION OF MIDCOURSE CORRECTIONS**
  - **RECOMMENDATIONS**
- **PREPARATION OF SESSION CHAIRMEN'S REPORTS TO PROGRAM MANAGEMENT**

## SESSION CHAIRMEN REPORTS TO PROGRAM MANAGEMENT

In general, only session chairmen and rapporteurs are invited to attend the feedback session. Thirty minutes has been allotted for each oral report, and about ten minutes of the allotted time should be reserved for questions and discussion. Written reports are also to be provided, but appropriate charts from the oral presentation should suffice. Written responses to recommendations will be provided within a few weeks following the workshop.

SESSION CHAIRMEN REPORTS TO PROGRAM MANAGEMENT		
LANGLEY RESEARCH CENTER BUILDING 1218, ROOM 107		
Thursday, May 16		
2:00 p.m.	Source Noise	Blaha/Preisser
2:30 p.m.	Aeroacoustics Analysis & Community Noise	Golub/Soderman
3:00 p.m.	Airframe Systems Studies	Dollyhigh/Kidwell
3:30 p.m.	Propulsion Systems Studies	Strack/Fishbach
4:00 p.m.	Airframe/Propulsion Integration	Batterton/Nelms
4:30 p.m.	Emissions Reduction	Niedzwieck/Langhoff
5:00 p.m.	Airframe & Engine Materials	Tenney/Herbell
Friday, May 17		
8:30 a.m.	Atmospheric Effects	Remsberg/Gross
9:00 a.m.	Laminar Flow Control	Fischer/Wolf
9:30 a.m.	High-Lift	Gilbert/Ross
10:00 a.m.	Sonic Boom (Aerodynamic Performance)	Darden/Hicks
10:30 a.m.	Sonic Boom (Human Response & Atm Effects)	Shepherd/McCurdy & McAninch/Wilshire
11:00 a.m.	Break	
11:15 a.m.	Executive Session	
Noon	Adjourn	

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## **Session II. Airframe Systems Studies**

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